University of Canterbury

Master's Thesis

Design and Development of an Energy Positive, Modular, Transportable Building

Author:
Sean Cooney

Supervisors:
Dr. Chris Hann
Assoc. Prof. Gregory MacRae

A thesis submitted in fulfilment of the requirements for the degree of Master of Engineering in Electrical and Computer Engineering

in the

Department of Electrical and Computer Engineering

June 2016

Abstract

This project has involved the design, development and modelling of a stand alone, transportable, renewable energies building. An experimental test apparatus was constructed that characterised the performance of a single panel Building Integrated PhotoVoltaic/Thermal Collector. The data collected from the test apparatus was used to aid in the design and modelling of a 9.4m by 3.6m building that includes 18 BIPV/T panels. After multiple revisions, a final building design was realised that satisfied all structural and aesthetic requirements. An extensive set of simulations were performed on this design to predict the thermal and electrical performance of the building. The results predicted a thermal energy deficit during winter months which had to be rectified with an auxiliary resistive heater to maintain a minimum internal zone temperature of 16°. The power system provided a reliable electricity supply for a minimum electrical storage of 11.2kWh. The complete construction cost for the design was $125,450.36 which includes a 20% profit margin and 15% GST. Comparisons to other currently available products were made but did not provide a definitive indication of the building's commercial viability. Calling on his wealth of experience, Brent Mettrick is confident that the building design could be successful in the market place.

Acknowledgements

Throughout this project I have received support and encouragement from many people. Without this support I am entirely sure I would not have been able to complete this undertaking.

First and foremost, I would like to thank Stonewood Homes and Callaghan Innovation for making this project possible with funding and resources.

Brent Mettrick, for sharing your commercial expertise and insights in to effective aesthetic design. Your advise and guidance has helped me to not only focus on technical engineering design aspects but to look the big picture to provide a well rounded attractive solution.

Dr Chris Hann, for initiating this project and bringing all the necessary people together to get it under way. Your support and endless optimism throughout the project has been a great help.

Greg MacRae, for sharing your technical expertise in construction and always encouraging me toward an effective solution.

Jody McMurdo, for putting up with me and answering all my technical questions, good and bad. I simply could not have achieved a workable building solution without your drafting and building knowledge.

Dennis Chapman, for your guidance in every area of the project. Your Eco-Castle inspired many of the design features in this project and your technology has perfectly complemented the final design.

Alastair McDowell, for your invaluable support in the thermal and electrical modelling of the building design in this project. Your modelling techniques and insight helped me to create a more effective, efficient design.

To my beautiful girlfriend Sara, for putting up with me during the highs and lows of this project. Your support has been one of the main things that has kept me going.

To my wonderful family (especially my mother) that have always supported me in everything that I do. Thank you for your ongoing support without which an achievement such as this would not have been possible.

A great big thanks to all of you.

Contents

List of Figures

List of Tables

Abbreviations

PIR	**P**oly**I**socyanu**R**ate
PV	**P**hoto**V**oltaic
BIPV/T	**B**uilding **I**ntegrated **P**hoto**V**oltaic / **T**hermal
NIWA	**N**ational **I**nstitute of **W**ater and **A**tmoshperic research
TRNSYS	**TRaN**sient **SYS**tem simulation
VCS	**V**entilated **C**oncrete **S**lab
ACH	**A**ir **C**hanges per **H**our
PWM	**P**ulse **W**idth **M**odulation
MPPT	**M**aximum **P**ower **P**oint **T**racking

Symbols

d	distance	m
P	power	W
k	thermal conductivity	$\mathrm{Wm^{-1}K^{-1}}$
C_p	specific heat	$\mathrm{jkg^{-1}\ K^{-1}}$
t	temperature	°C
Q	thermal energy gain	W
$\dot{m}$	air or water flow	$\mathrm{kgs^{-1}}$
A	area	$\mathrm{m^2}$
G_T	solar radiation	W
ω	angular frequency	$\mathrm{rads^{-1}}$
ρ	density	$\mathrm{kgm^{-1}}$
τ	time	s
η	efficiency	

Chapter 1

Introduction

The need for sustainable energies housing has become more apparent in the last 20 years. Energy Prices and concerns for Global Warming are continuing to increase, which is creating a demand for a change in building techniques and the wider inclusion of renewable energy systems. Photo-Voltaic electricity generation is leading the way in pursuit of 'Clean, Green' living.

Residential homes in New Zealand use a significant proportion of energy on space heating and hot water at 34% and 29% respectively [3]. With careful building and solar energy systems design, it is possible to satisfy this usage entirely with renewable energy. Retrofitting solar PV and hot water systems has become a viable option, with acceptable payback periods and performance, but in many cases retrofitting is cost prohibitive.

A Building Integrated Photo-Voltaic Thermal (BIPV/T) unit is a combined electrical and thermal energy collector built in to a new building structure. BIPV/T systems are well documented and are used all over the world to varying degrees of success with the basic principle of harvesting heat energy from the back of a PV panel. For a given solar radiation, typically only around 16% can be converted in to electrical energy by a PV panel due to reflection and cell heating. The heat generated in the cells would normally be vented to outside air which could be otherwise harnessed and used for general domestic heating duties.

Stonewood Homes Ltd is already pushing clients toward Energy Efficient builds with the advent of the Solar Ready Home and the optional HomeStar ratings. Stonewood

Homes Ltd are committed to the continual betterment of their building techniques and provide almost limitless customization to client's specifications.

1.1 Project Partners

1.1.1 Stonewood Homes

Stonewood Homes NZ Ltd are one of the largest home builders in New Zealand having built over 4000 homes throughout the country since being established in 1987. Christchurch is their largest market with build numbers rising explosively with the advent of the 'Christchurch Rebuild'.

The head office is in Christchurch which houses multiple financial, administrative and technical teams to support the wider franchise network. The Drafting team cater to all South Island franchises providing building detailing and modelling and managing the consent process for each new build. The corporate costing team provide detailed costing information for standard plan options that are available to clients through franchises. The Christchurch building also houses the Christchurch regional Stonewood Franchise.

Stonewood Homes currently offer 'Green' energy efficient options when building a home, with one of their show homes being the first to achieve a 7 Star Homestar rating. Every home built by Stonewood is now labeled a 'Solar Ready Home' as EnaSolar Grid Tie Inverters are mandatory equipment for new builds. The client can then choose to have PV panels installed to complete the renewable energy system.

The project outlined in this report will add to the company's existing knowledge base in energy efficient housing and renewable generation systems. The resulting design will be a potential saleable product to be added to the Stonewood product lineup.

1.1.2 DARC Technologies

DARC Technologies was formed in 2008 as a technology development company, funded by Dennis and Alan Chapman. The company's primary purpose was the development of electronic solutions to be deployed in the Eco-Castle.

Most of their current solutions are based around the use of SoPLC (Signal over Power Line Carrier) technology. Listed below are some of their products that are in production phase:

- 100W Hi-bay LED Industrial Light
- 40W Uplight
- 48V 4-Channel Driver
- 48V Bi-directional 4 Channel Driver
- 1-6 way switch plates

These solutions, if proven successful in the Eco-Castle, will be evaluated for future commercialisation targeting both the domestic and commercial building industries.

In conjunction with the project outlined in this proposal, DARC Technologies has taken on another Masters Student, Alastair McDowell, to work on a thermal modelling project. This modelling system will be capable of calculating the overall energy gain of a building, both Thermal and Electrical (with PV Panels). The model will be tested and verified on the building that will be constructed during the course of this project.

1.2 Problem statement and focus

The building industry in New Zealand has come a long way in the last 50 years, with many standards being conceived and refined that cater to our unique range of environmental conditions. Despite the development of such standards, new residential homes still consume relatively large quantities of electrical energy from The Grid.

The New Zealand Grid is supplied by mostly renewable energy sources, but there is still a large proportion that is supplied by fossil fuels. Distributed generation has been hailed by many as the energy solution of the future due to its inherent efficiency from lack of inefficient transmission. Distributed generation includes any power source that is local to where the energy is being consumed. This can consist of both renewable and non-renewable sources.

Small scale sustainable energy systems are now widely available to be retrofitted to any residential building and can offer acceptable financial and environmental returns. These systems are becoming more viable as Energy Prices from The Grid increase. While these systems can provide acceptable returns, systems that are incorporated in a building's initial design can provide substantially higher returns.

Building integrated renewable energies systems are inherently more efficient due their design-for-application nature. This higher efficiency, along with a lower capital cost contribute to a superior system both financially and environmentally. Economic Distributed Generation will never truly be realized until these systems are incorporated in new residential buildings.

1.3 Research Objective

Building integrated renewable energy systems are on the rise globally but have not yet taken hold in New Zealand. The main reason is the capital costs associated with the systems but also the relatively low energy efficiency standards in New Zealand.

The goals of this project are two-fold; to design an energy and cost efficient Transportable building and to provide Stonewood Homes Ltd with useful Intellectual Property pertaining to the sustainable design of new residential buildings. The key idea's that will be developed during this project are:

- Extensive use of internal, fully insulated thermal mass
- Building Integrated Photovoltaic / Thermal System
- Solar Energy gain (Electrical and Thermal)
- Heat controlled ventilation

The project will focus on techniques for integrating all of these components in to a new residential building in a cost effective manner and in such a way as to not disrupt the usability of the building when compared to a 'standard' residential build.

Support staff from Stonewood Homes Ltd will assist with a lot of the low level technical details so that this project can focus on mostly high level designs and analysis.

Chapter 2

Background

Highly insulated, energy efficient homes are not a new concept. New homes are now required to be insulated to a certain standard to ensure a safe living environment for its occupants as stipulated by the independent research, testing and consulting organisation, BRANZ Ltd. This standard is a step in the right direction, but the ideal home would require little or no energy from The Grid (National Electricity Grid) to maintain a comfortable and healthy indoor temperature and air quality.

The greatest challenge with energy efficient buildings is making them cost efficient. Energy efficient buildings have obvious long term cost benefits, but market uptake is and always will be largely dependent on the upfront capital value. Therefore building companies are being driven to look for more cost and time efficient materials to lower the capital cost of energy efficient buildings.

Transportable buildings are inherently time efficient as they can be constructed in highly efficient factories before being moved to site. This efficiency almost eliminates dependence on appropriate weather conditions and greatly reduces down time and required project management for a given implementation.

2.1 Thermal Mass

In the context of a building, thermal mass is any indoor material that has a significant specific heat capacity, and acts as thermal storage, absorbing heat during the day and releasing it at night. If a building is designed with substantial use of concrete or some other material with a high specific heat capacity, it has the effect of reducing temperature fluctuations within the building. This behaviour not only decreases negative fluctuations in indoor temperature below what is comfortable, but will decrease positive fluctuations in the case of excessive available solar, or other, heat energy.

Zeng et al. [4] states that the effect of thermal mass can be evaluated by considering the dynamic indoor temperature as a function of a building's total thermophysical properties (with no active heating or cooling).

$$t_{in} = k(t), \rho C_p(t), ACH(\tau) \tag{2.1}$$

where t is temperature, k is thermal conductivity, ρ is density, C_P is specific heat, ACH is air changes per hour and τ is time.

Zeng et al. [4] proposes that traditional methods of building are flawed in the way that the building's thermophysical properties are generally non-variable and are not suited to specific climate information and thermal comfort demand. It is stated that a new approach should consider the climate information, thermal disturbance, building geometry, and thermal comfort demand for a given application. From this approach the optimal thermophysical properties of the building can be determined to best take advantage of natural resources.

Kalogirou et al. [5] investigated the effect of deploying thermal mass in Cyprus with a simplified model of a single zone building. After optimisation of the quantity of thermal mass and various building parameters, the simulation showed a decrease in the average heating load of 47%.

2.2 Solar Energy Gain

It is generally considered cost effective to design buildings that make optimal use of solar energy resources. Both thermal and electrical energy can be utilised to minimise dependence on traditional energy sources such as the National Electricity Grid.

Northward facing window area is maximised to increase incident radiant energy on internal building materials, preferably those with high specific heat capacity. With this thermal gain, careful consideration needs to be made to avoid building overheating during times of high solar resources. Roof overhang lengths and angles are tailored to reduce incident radiant thermal energy in summer months.

The Building Research Establishment Trust [6] outlines the fundamental design characteristics design to meet the stringent PassivHaus building standard. One of the main aspects of the standard surrounds the extensive utilisation of solar irradiation to passively heat a building. With careful design and construction, buildings can be designed to use very little to no energy for space heating.

Photovoltaic Cells have made huge advancements in the last decade, to the point where they are now becoming a very cost effective residential electricity solution. Retrofitting PV panels can still be financially viable, but the maximum benefit is realised when the PV panels are integrated in to the design of new buildings.

2.3 Building Integrated Photovoltaic / Thermal

Photovoltaic / Thermal systems combine two methods of solar energy collection in to one size and energy efficient system. A typical PV/T system uses a silicon PV panel as the primary collector which generates electrical power, with a working fluid removing the generated heat from the rear of the panel. As PV/T systems have a relatively high capital cost a common method for reducing that is to integrate the system in to the buildings design, hence the full name, BIPV/T.

BIPV/T systems are a well documented method of decreasing a building's reliance on traditional energy sources. Chen et al. [7] performed the modelling, design and performance assessment for a BIPV/T system thermally coupled to a Ventilated Concrete Slab (VCS) in a low energy solar house that was constructed in 2007 in Quebec, Canada. The BIPV/T system was found to achieve a typical efficiency of around 20%. The building was highly insulated including large south facing triple glazed windows increasing passive solar gains. The building's space heating energy consumption was about 5% of the national average.

Kim et al. [8] analysed a experimental BIPV/T system that utilised water as the working fluid. The water can be used in buildings to supplement existing hot water supply, or for space heating with the use of a suitable radiator. The experimental results showed an average thermal efficiency of 30%.

Water type PV/T systems exhibit greater thermal efficiency due to the working fluid having far greater heat capacity and conduction rates when compared to that of air. The down side of using water as the working fluid is the increased cost of having to contain and distribute the water throughout the system.

Zogou & Stapountzis [1] constructed a BIPV/T experimental test rig using air as the working fluid, shown in Figure 2.1. The PV module used was a commercially available 205W multi-crystalline unit. The experimental unit exhibited an average thermal efficiency of around 8% which was attributed to characterised attributes of the air flow within the unit.

FIGURE 2.1: BIPV/T test rig as constructed by Zogou & Stapountzis [1]

2.4 Heat Controlled Ventilation

Modern HVAC (Heating Ventilation Air-Conditioning) systems are constantly being pushed toward being more energy efficient. A major contributor to energy efficiency in these systems is the style of ventilation they employ.

Traditional residential buildings do not utilise any kind of active ventilation but adhere to the building standard, which requires a minimum area of opening windows as stipulated by their given floor area. This standard results in very high heat losses if ventilation is maintained at an adequate level. Typically, to maintain a warm environment at evening and night times, all windows and doors will be closed, which reduces ventilation to only the buildings characteristic infiltration rate. This rate effectively retains the maximum amount of thermal energy within the building, but can lead to increased concentrations of CO_2 and other pollutants.

Ventilation can be performed through a high efficiency heat exchanger to dramatically reduce associated heat losses. Exhaust indoor air is passed through a counter cross-flow heat exchanger which passes heat to, or accepts heat from, incoming outdoor air. This process is known as an HRV (Heat Recovery Ventilation) System or an air-to-air heat recovery unit.

Fernández-Seara et al. [2] performed an experimental analysis of an air-to-air heat recovery unit in a residential building. A maximum thermal efficiency of 94% was achieved at air flow rate of $50m^3/h$ and it was observed that while the thermal transfer increased with an increase in air flow, the thermal efficiency dropped to 78% at an air flow rate of $175m^3/h$. Under steady operation, the heat transfer rate and the thermal efficiency were accurately measured at 672W and 80% respectively which could amount to significant thermal energy conservation in a residential building. Figure 2.2 shows the heat recovery unit used as the test apparatus.

2.5 Eco-Castle

In 2010 construction began on Dennis Chapman's Eco-Castle, officially completed in 2015. The building serves as a residence for Dennis and Debby Chapman as well as

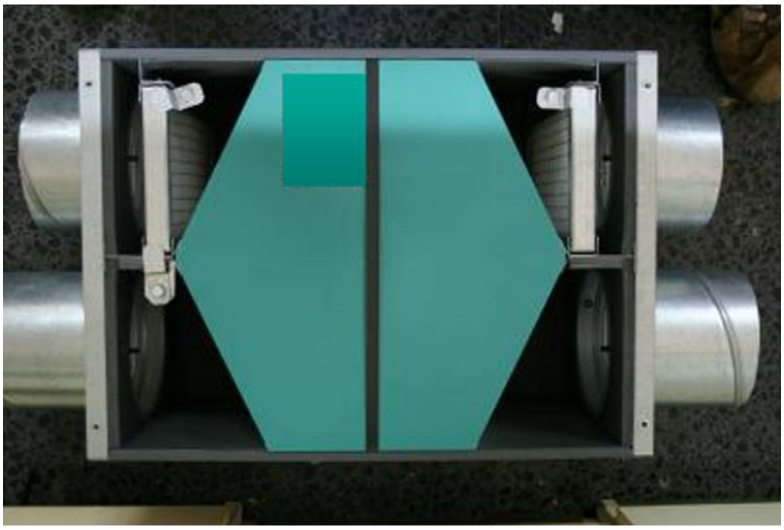


FIGURE 2.2: Heat recovery unit used as the test apparatus for investigations performed by Fernández-Seara et al. [2]

offices for Darc Technologies. The building is capable of being completely energy self-sufficient with an installed solar PV capacity of 22.6kW. The PV panels are part of the installed BIPV/T system which is capable of generating up to 30kW of heat. Many of the basic concepts of this building were used in the design process of this project. Figure 2.3 is a photograph of the front of Dennis Chapman's Eco-Castle showing the use of Building Integrated PV panels.

FIGURE 2.3: Front View of Dennis Chapman's Eco-Castle

2.5.1 BIPV/T

The Eco-Castle incorporates a very sophisticated BIPV/T system that generates sufficient heat to maintain a comfortable indoor temperature throughout the year. The thermal system that is connected to the BIPV/T system is a hybrid of air and water. Air is passed underneath the PV panels to collect the solar energy which can be either recirculated within the building for direct space heating, or is transferred to water via two 15kW heat pumps. The water is stored in tanks and ultimately circulated through the floor slabs for thermal storage.

One of the key design features of the BIPV/T system is the use of the PV panels as the primary weather tight envelope of the building. Dennis Chapman commissioned the design of an extruded aluminium frame that is built around a standard size glass covered solar cell array. The frames are designed to have extruded aluminium clips that lock regular flashing profiles in to place to seal the panel array to the sides of the building. All junctions of the panels are sealed with custom designed extruded rubber profiles.

Alastair McDowell created an accurate thermal model of specific parts of the Eco-Castle to characterise the systems performance. It was found that the BIPV/T system was able to produce a minimum of 350kWh per day during the winter of 2015. The thermal and HVAC (Heating Ventilation and Air Conditioning) systems are currently being optimised by Darc Technologies to make best use of the available resources with the aim of arriving at a reliable system that can maintain comfortable indoor conditions year round.

2.5.2 Signal Over Power Line

The traditional method for wiring follows the current electrical standards with mechanical switches directly energising 230V AC (Alternating Current) loads, however, the Eco-Castle is wired with 230V AC and 48V DC (Direct Current) bus's throughout the building.

Each switch and load have a micro-controller based circuit that act as a master node and slave node respectively. These nodes connect directly to the 48V DC bus and communicate though the bus using a high frequency signal. Any master node can control any slave node on the bus by programming the appropriate node ID's in to the micro-controller's.

This system greatly reduces the cost of wiring a building and allows for greater flexibility and reconfigurability. The 48V supply is also considered low voltage and non-lethal.

2.5.3 LED Lighting

Darc Technologies have designed LED lighting components that compliment their Signal Over Power Line system. The production ready lights will feature built-in circuits that will directly connect to the 48V bus within a building. The lights are designed to be energy efficient while still providing exceptional aesthetic appeal.

Chapter 3

Experimental Design

Darc Technologies have provided their proprietary solar panel fastening system that provides BIPVT capability when incorporated in to a new build design. The system uses the solar panels to seal the envelope of the building, allowing for a thermal air duct beneath the panels.

An experimental thermal test rig was constructed in conjunction with Alastair McDowell to determine the thermal characteristics of the PV panel that would be used in the design in this project. The test was made to simulate as closely as possible the intended final roof design of the building so that the data could aid in the effective design of the energy system. Figure 3.1 and 3.2 show the construction stages and the final thermal test rig.

Figure 3.1: Thermal Rig Constructional Layer View

The rig was built from sheet plywood and various timber sections to form a closed loop thermal system. The heat energy harvested from the back of the PV panel was cycled around the ducted loop which fed into a water to air heat exchanger the remove the heat from the system. All temperatures and flow rates were monitored to gain a comprehensive data set for later analysis.

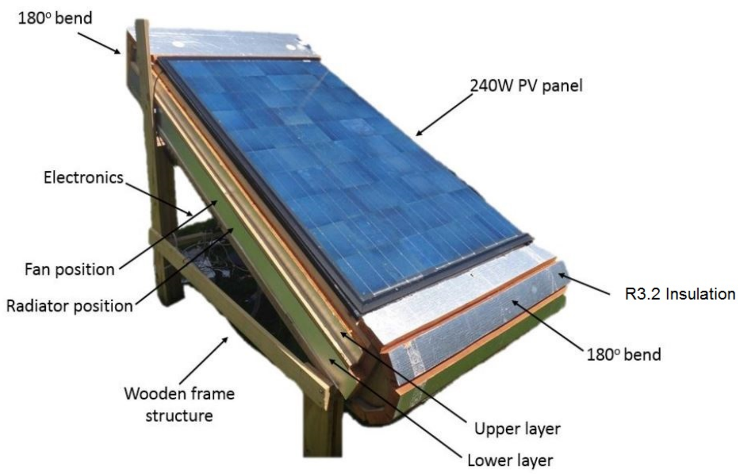


FIGURE 3.2: Thermal Rig Main View

The design of Figure 3.2 was modelled on the Eco-Castle thermal system so that the results were realistic and suitable for use in the design of the transportable building. The Test Rig measures two basic quantities; Electrical Energy output and Heat Energy output. The entire envelope of the Rig is insulated with plywood and foam to ensure accurate thermal readings. Table 3.1 shows the specifications of the BIPV/T Thermal Test Rig.

TABLE 3.1: Experimental BIPV/T Specifications

Specification	**Symbol**	**Value**	**Unit**
Max Power	P_{mp}	240	W
Max Power Voltage	V_{mp}	30.0	V
Max Power Current	I_{mp}	8.01	A
Open Circuit Voltage	V_{oc}	36.8	V
Short Circuit Current	I_{sc}	8.6	A
Cell Efficiency	η_{cell}	16.8	%
Module Efficiency	η_{module}	14.9	%
Temp Coefficient	α_p	-0.434	$\%/°C$
Nom. Cell Temp	NOCT	45	°C
PV Aperture Area	A_{PV}	1.65	m^2
Tilt Angle	β	30	°
Azimuth Angle	γ	180	°
Channel Depth	d	0.1	m
Channel Length	L	1.6	m
Maximum Air Flow Rate	$\dot{V}_a$	0.19	m^3/s
Maximum Water Flow Rate	$\dot{V}_w$	2.5	L/min

3.1 Electrical Energy System

The objective of this system was to extract the maximum possible amount of Electrical Energy from the PV Panel. For the purpose of this application, the energy extracted needed to be measured and then exited from the system. A load resistor was used to convert the electrical energy in to heat energy to be vented to the atmosphere.

3.1.1 PV Control Circuit

An Atmel Microcontroller was used to control an N-Channel MOSFET to switch a load resistor and data-log the Voltage and Current of the PV Panel. The power circuit is a simple low side switch actuated by Pulse Width Modulation (PWM) to attain a variable voltage source to the load therefore adjusting the effective load on the PV panel. The PV panel voltage is filtered with the use of a large array of capacitors to ensure the voltage and current remain steady ensuring accurate Maximum Power Point Tracking operation.

The voltage of the PV panel was scaled down using a resistor divider and current was measured using a current shunt resistor and shunt monitor Integrated Circuit (IC). Figure 3.3 shows the installed Microcontroller and power circuits.

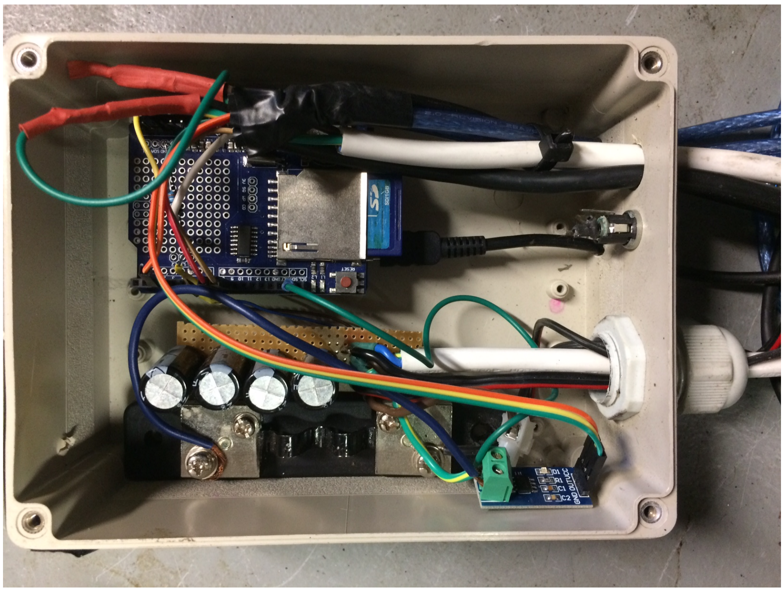


FIGURE 3.3: Microcontroller and Power Electronic Circuits

3.1.2 Maximum Power Point Tracking

The Maximum Power Point Tracking (MPPT) algorithm employed was 'Perturb and Observe'. This simple solution provides acceptable accuracy with minimal tuning. The other main MPPT algorithm considered was Incremental Conductance but this method gave insignificant improvement in accuracy over the 'Perturb and Observe' method for significantly higher complexity.

The basic premise of the 'Perturb and Observe' method is to begin at a pre-programmed base load, then to keep increasing load while power is increasing. When a point is reached where the power output starts to decrease the load will be decreased to attempt to again increase power output. Figure 3.4 shows a flow diagram of the basic perturb and observe algorithm.

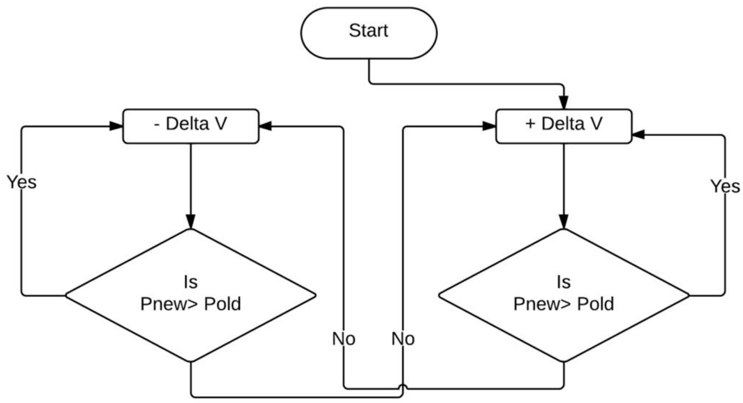


FIGURE 3.4: Perturb and Observe Algorithm

This process begins a cycle around the load point at which maximum power output is achieved. With an appropriate time scale for load adjustment, this method achieves excellent response to changes in available solar resources. Voltage, Current and Power of the PV panel were data logged to a Comma Separated Values (CSV) file on an attached SD Card every 10 Seconds for later analysis.

3.1.3 Electrical Efficiency

The PV panels specified for the building design utilize a silicon polycrystalline cell construction. This construction type is not as efficient as silicon monocrystalline cells, but is markedly cheaper per rated Watt. The power output and subsequent efficiency of a given PV array is determined by two primary factors: the incident solar irradiation, and the operation temperature of the cells. Commercially available cells will typically be rated at a solar irradiation of 1000W/m2 and a cell temperature of 25°C.

Appendix A shows the data sheet for the PV panels that will be used in this project (TP-245P). The data sheet shows a rated efficiency of 14.97% at 1000W/m2 with a cell temperature of 25°C. The thermal derating factor shown is -0.41%/°C.

3.2 Thermal Energy System

3.2.1 Construction Methods

The Thermal Energy system in the Test Rig was closed loop to ensure accurate measurement of captured Heat Energy. The closed loop of the system was created with two flat, rectangular ducts placed on top of each other with joined ends to create a complete flow path. Air was circulated through the ducting by four 120mm computer fans with heat being extracted by an aluminium Air to Water Heat Exchanger fed from a constant-flow water supply. Figure 3.5 shows a profile view of the thermal energy system.

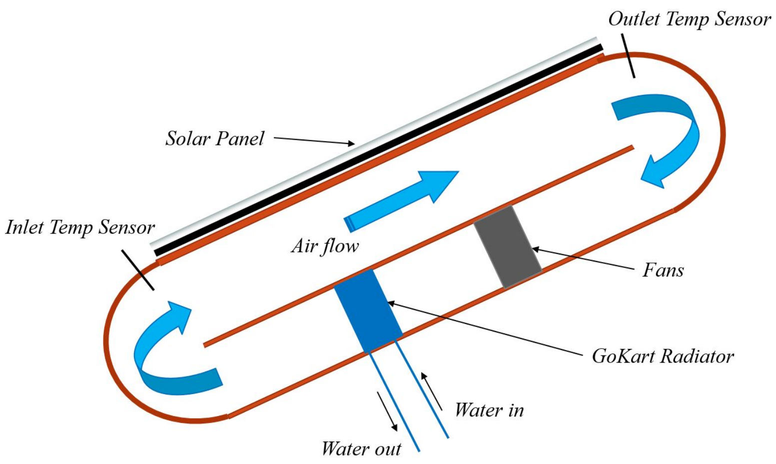


Figure 3.5: Thermal Rig Operational Layout

R3.2 foam insulation surrounded the entire envelope of the thermal ducts to insulate the system. A simple calculation of the heat loss through the insulation was performed to confirm that it would have a negligible effect on the measured values. Figure 3.6 shows the same profile view as in Figure 3.5 but with the surfaces subjected to heated air indicated along with their respective construction materials and R values.

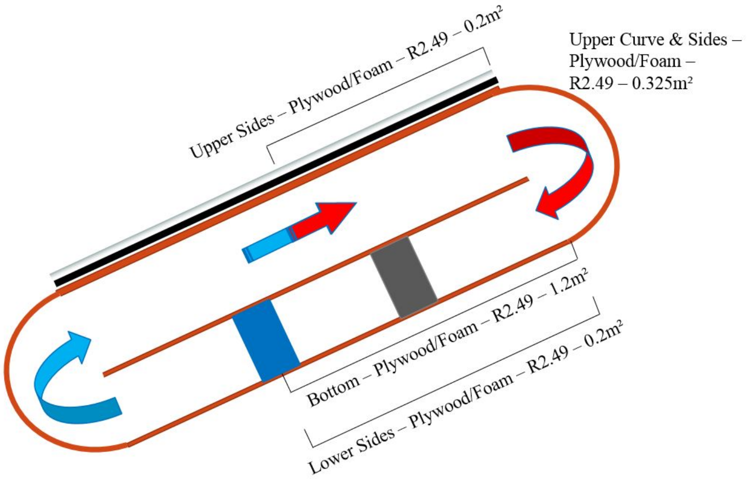


FIGURE 3.6: R Values of Thermal Rig Construction Materials

The maximum air temperature differential recorded between the outlet of the PV panel and the ambient air while operating was 2.8°C. Summing the accumulated heat loss over the heated surfaces gives a total heat loss of 2.2W. At this particular data point the output thermal power was measured at 144W resulting in a proportional power loss of 1.5%. This result was used to adjust the data taken from the test rig.

3.2.2 Instrumentation

The Thermal data logging is performed by a Signal-Over-Powerline system curtesy of DARC Technologies. This system is currently used in the Eco-Castle to control and datalog all electrical systems. The Ballast Unit and Signal-Over-Powerline system will be further detailed in Chapter 5. Figure 3.7 shows an example USB Transceiver unit and Input/Output Ballast Driver.

The unit in this application powered the four fans, and measured and logged the inlet and outlet water temperatures and the flow rate of the water. The output data was logged to a CSV file for later analysis.

The Micro-controller also used three digital temperature sensors to measure and data-log the Inlet, Outlet and Ambient Air Temperatures of the Test Rig.

Sensors/instruments used to measure quantities in the system are listed as follows:

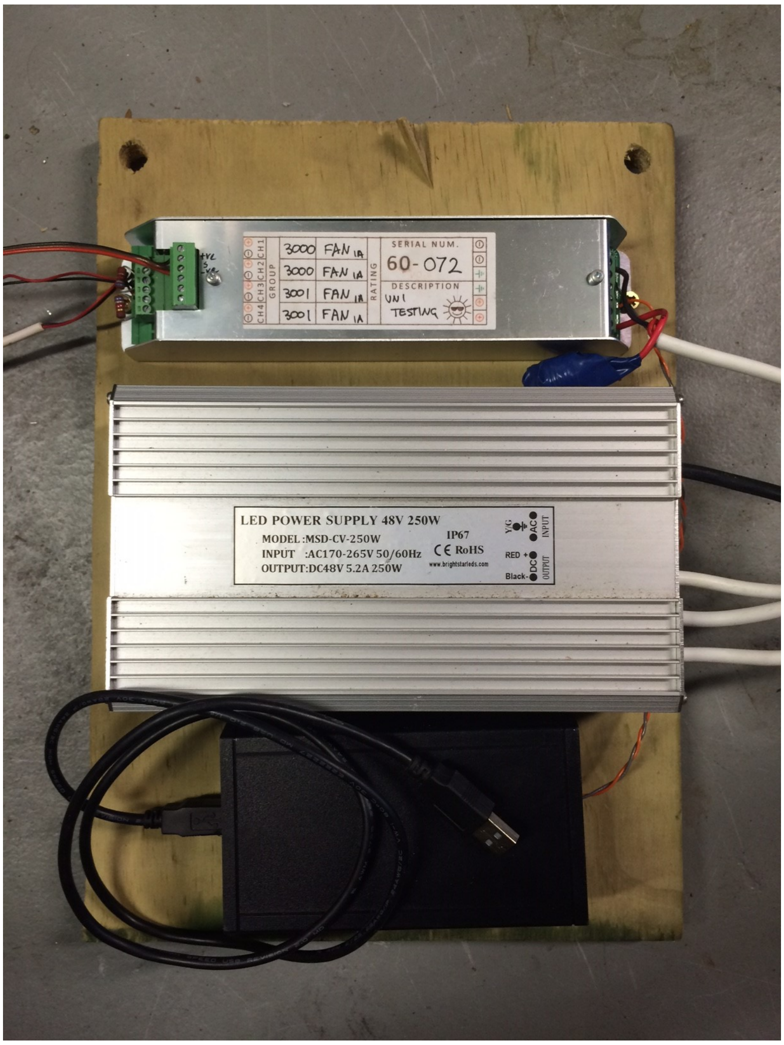


FIGURE 3.7: DARC Technologies Ballast, 48V Switching Power Supply, USB Serial Tranceiver

Air Flow Rate A hot wire anemometer was used to measure the velocity of the air within the Test Rig at multiple points. These velocity measurements were averaged and then multiplied by the duct area to gain an average bulk air flow rate.

Water Flow Rate A 6mm hall effect water flow sensor was used to directly measure the water flow rate. This sensor is designed to be accurate for flow rates between 0.3 - 3.0L/min. The typical flow rate of the tests were 2.5L/min. The sensor was further calibrated by the timed filling of a container of known volume.

Water and Air Temperatures Water temperatures in the system are measured with calibrated K-type thermocouples. Air temperatures are measured with digital temperature sensors. All sensors used are accurate to 0.1°C.

Solar Irradiance An Apogee CS300 solar pyranometer is used to measure solar irradiance. Total solar radiation can be measured to with 5%. The device is mounted at the Chapman Eco-Castle.

3.2.3 Output & Efficiency Equations

Two methods of measuring Thermal Energy gain were used. The mass flow rate of the air was held constant and measured along with the inlet and outlet air temperatures of the PV under-panel ducting. Similarly the flow rate of the water to the heat exchanger was held constant and measured along with the inlet and outlet temperatures of the water. Both of these methods can be used to calculate power output and should follow very similar trends, only differing by the effect of Thermal Inertia of radiator and the water it contains. The sensors and fans are labelled in Figure 3.5. The useful thermal energy gained from the system can be defined:

$$Q = \dot{m}C_p(T_{in} - T_{out}) \tag{3.1}$$

where $\dot{m}$ is the air or water flow into the system, C_p is the specific heat capacity of air or water, and $T_{in} - T_{out}$ is the differential between the inlet and outlet temperatures .

The energy harvested from the thermal collector was the primary quantity of interest in the design of the building's energy system, however to compare the collector to other available systems the efficiency must be determined. The efficiency of the solar thermal collector can be defined:

$$\eta = \frac{Q}{A_{PV}G_T} \tag{3.2}$$

The efficiency of the collector η is calculated from the thermal energy gain Q, the area of the collector A_{PV}, and the incident solar radiation G_T.

The total energy available to the system is the product of A_{pv} and G_T. In the case of a BIPT/T system, the area of the collector is fixed. The incident irradiation G_T can be calculated from the measured solar radiation on the horizontal surface of the Apogee CS300 Pyranometer, the tilted surface slope angle β, and azimuth angle γ.

The total measured horizontal solar radiation G_H is first broken down in to the beam radiation G_B, and the diffuse radiation G_D. The total radiation on a tilted surface G_T is then defined:

$$G_T = G_B R_B + G_D \left(\frac{1 + cos\beta}{2} \right) + G_H \left(\frac{1 - cos\beta}{2} \right) \tag{3.3}$$

where R_B is the geometric factor that determines the position of the sun in the sky.

Chapter 4

Structural Design Development

The Structural Design of the building is governed by four main aspects:

- Thermal performance
- Aesthetic appeal
- Usability
- Cost of Manufacture

The focus of the design in this project is the use of materials that are, or are close to, pre-finished, saving greatly on labour intensive build operations. This saving on labour expenses allows the use of high performing materials, contributing to superior overall thermal performance.

The initial structural guidelines of the project as stipulated by Dennis Chapman and Brent Mettrick are as follows:

- Permanent and Dynamic Thermal mass would be introduced with the use of a concrete foundation with cast-in water tanks
- PIR/Steel sandwich panels sourced from Conqueror Panels LTD would be utilised for the entire envelope of the build due to their high structural strength and unrivalled thermal performance
- The BIPVT system used in the Eco-Castle would be adapted for use on the building

- A minimum of opening windows would be used to increase thermal performance. Active Mechanical ventilation would be substituted in its place

- Majority of window area would be North facing to increase Solar Energy Gain

- Single Bedroom with Living Room / Kitchen and Bathroom

- Must be relatively easily transported

This chapter will outline the design process taken to arrive at the final building concept.

4.1 Building Plan

4.1.1 Initial Building Plan

The requirements of the building plan design were to meet the above specifications of a Single Bedroom with Living Room, Kitchen and Bathroom, mainly north facing windows and a minimalist layout for ease of manufacture. The Kitchen and Bathroom were to be placed adjacent to simplify the installation of services and the layout would allow north facing windows in the Bedroom and Living room. With these basic specifications taken into account, and initial Building Plan was created as shown in Figure 4.1.

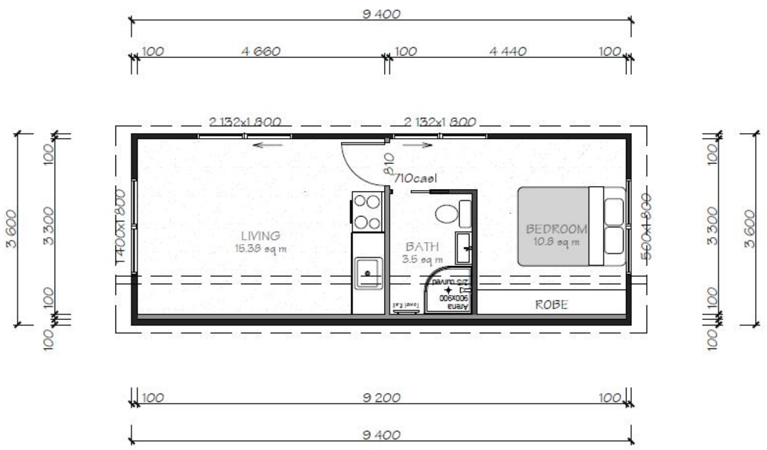


FIGURE 4.1: Initial Building Plan View

There are no south facing windows in the above plan as they would have a significant negative effect on the thermal performance of the design while providing little in terms of aesthetic appeal as sufficient glazing is provided on the East, West and North walls. Two slider doors on the North side of the building provide access to the bed and living rooms and provide sufficient North facing glazing to encourage thermal gain from incident solar resources.

The other specification to be considered is the overall size as Land Transport have size restrictions for transporting large objects. The above floor plan has been restrained to a 3.6m width to stay within the class 1 oversize transportation which does not require any special permits for transportation. The length of the building could be up to 12 meters and still fit on a standard size transportation trailer as 12m is the largest standard size shipping container.

Note that the rear wall of the building is 200 millimetres thick. The increased thickness is due to the initial design including a tilt slab inner wall to increase the interior thermal mass of the building, and is further detailed in the next Sub-section.

4.1.2 Final Building Plan

The building plan went through many changes for various aesthetic and technical reasons. Appendix C shows all Drafted concept versions. Figure 4.2 shows the Final Building Plan.

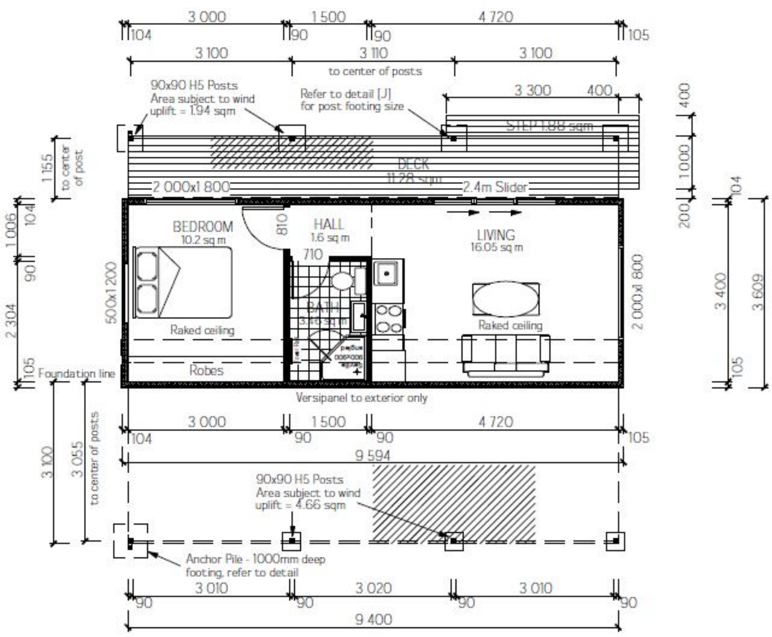


FIGURE 4.2: Final Building Plan View

There are many major and minor changes of figure 4.3 when compared to the Initial Design of figure 4.1. The building has been mirrored to increase solar resources to the Living room early in the day. The concrete tilt slabs have been removed as they did not significantly increase thermal performance of the building while being difficult and costly to construct. An Awning, Deck and Carport have been added to increase aesthetic and functional attractiveness for potential purchasers, as per the revised specifications given by Brent Mettrick.

4.1.3 Extended Building Plan

Dennis Chapman requested that a Two-Bedroom plan be created to cater for more than one or two inhabitants. Figure 4.3 shows the Two-Bedroom building plan.

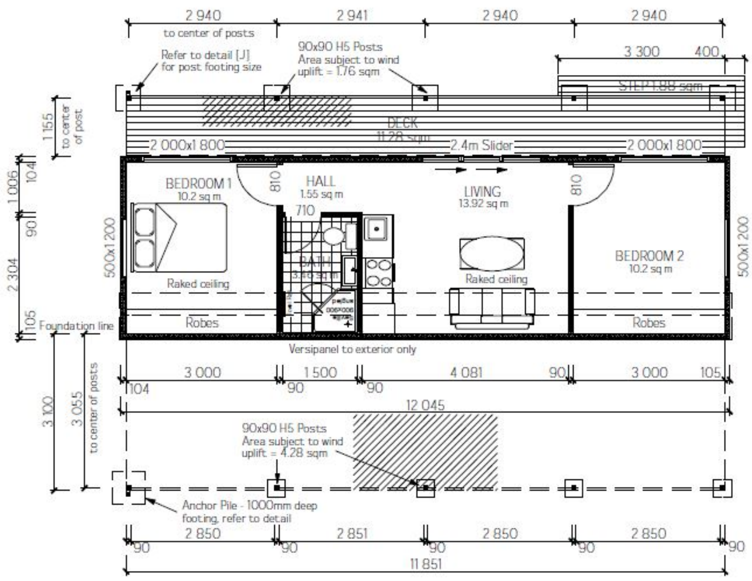


FIGURE 4.3: Two Bedroom Building Plan View

This plan reaches the 12m limit for transportation while providing two bedrooms and an acceptably sized living room. The increase in length also allows for more solar panels to be utilized on the roof thus providing the extra energy required for additional inhabitants.

4.1.4 Modular Building Plan

The design of Figure 4.3 lends itself well to being modularised due to its small footprint and transportability. The most basic configuration is to position two buildings back-to-back, creating a transportable building with up to three bedrooms. Figure 4.4 shows the building plan of two standard designs back-to-back.

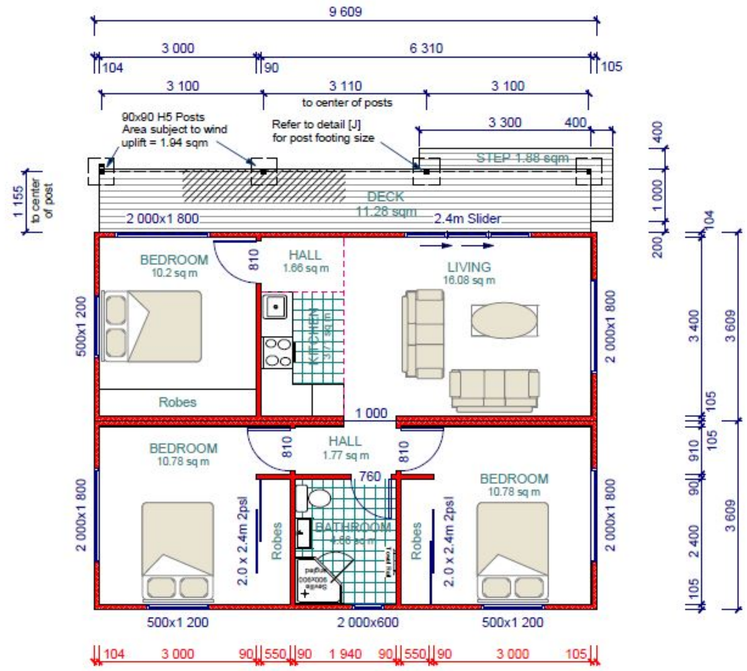


FIGURE 4.4: Two Unit Modular Building Plan View

This configuration offers flexibility for transportation, but the primary downfall is the reduction in energy efficiency. There is a significant increase in thermally conductive area while the North facing area of the building remains constant. Hence there is an increased chance of an energy deficiency in the complete off grid system.

4.2 Foundation

Dennis Chapman first proposed the idea of a transportable concrete foundation with cast in water tanks to equip the building with a large thermal mass. The concrete provides a permanent base thermal mass, and the water tanks create a dynamic thermal mass, which eases lifting requirements and introduces the benefit of having local water storage.

4.2.1 Waffle Slab

The slab is similar in design to a common Waffle Floor Slab or 'Rib-Raft' Slab, as it is more commonly known in New Zealand. A typical Waffle Floor Slab consists of an array of steel reinforced concrete beams with expanded polystyrene pods cast into the voids between the beams to provide insulation and a convenient form work while pouring the concrete. Figures 4.5 and 4.6 show a cross section and plan view respectively of a typical Waffle Slab.

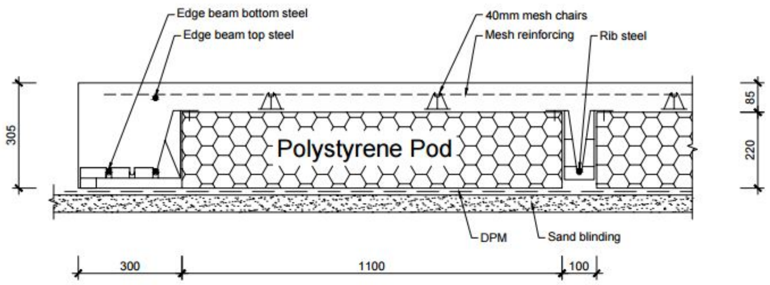


Figure 4.5: Rib-Raft Cross Section

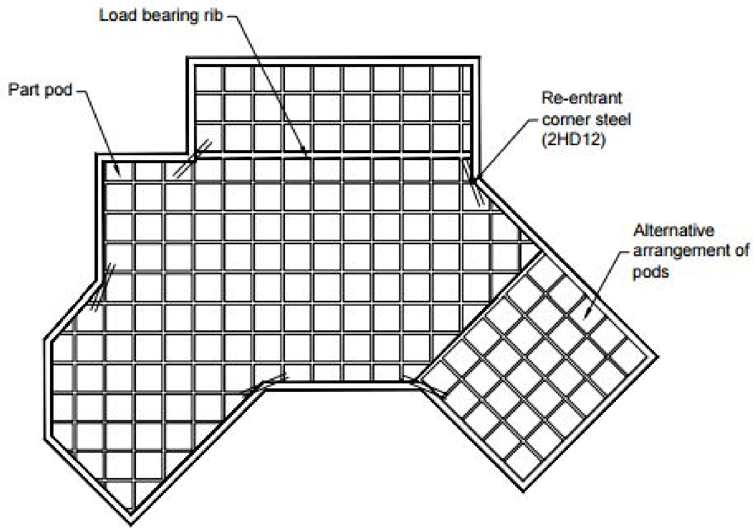


Figure 4.6: Rib-Raft Beam and Pod Layout

This Slab Design provides a very strong, stiff foundation with a relatively good insulation coefficient due to the large area of polystyrene pods. This design has been particularly favoured in the wake of the Christchurch Earthquakes as it provides the extra strength required for low quality ground conditions.

4.2.2 Tilt Slab Walls

The primary reason a concrete slab was chosen for the floor/foundation type is due to its inherently high thermal mass. The thermal mass in the building can be further increased with the use of interior concrete tilt slab walls. An additional benefit of an interior tilt slab is the thermal gain from incident solar radiation, provided that the slabs are uncovered and are exposed to solar radiation through appropriately positioned glazing. Figure 4.7 shows the proposed tilt slab wall design.

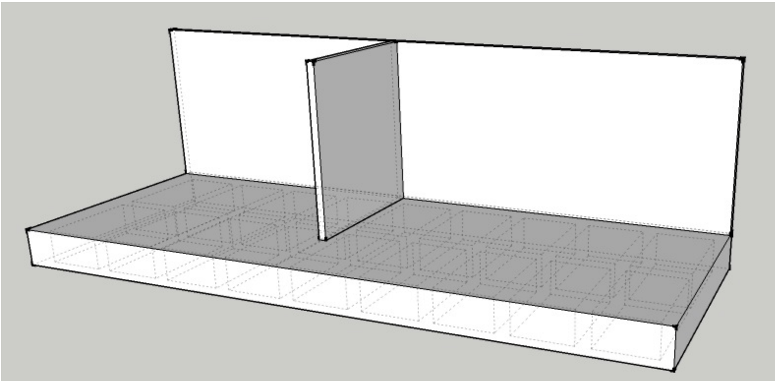


FIGURE 4.7: Initial Slab Design with Tilt-Slab Walls

Only the rear and centre walls are concrete slab as they require no cut outs for windows or doors. As well as providing thermal mass, the tilt slabs are load bearing and provide bracing to their respective walls. This approach simplifies the design of the panel fastening system as less load bearing and bracing members need to be designed in to the remaining super-structure.

4.2.3 Initial Foundation Design

The typical Waffle Slab foundation design provides a relatively well insulated and strong sub-structure, but can be improved to increase a building's thermal performance and usability. The Polystyrene Pods are a convenient form work for the concrete and have a high insulation coefficient but their use can be considered a waste of usable space within the building design. The concrete beams of the foundation lay directly on the prepared site surface allowing a relatively low resistance path for heat to be conducted to the earth below.

In this design the Polystyrene Pods would be replaced with Rotomoulded Polyethylene water tanks for the purpose of providing a dynamic thermal mass. Dennis Chapman initially provided a water tank design that he had intended to use in his 'Cube House' design. Figure 4.8 shows the drawings of the initial water tank design.

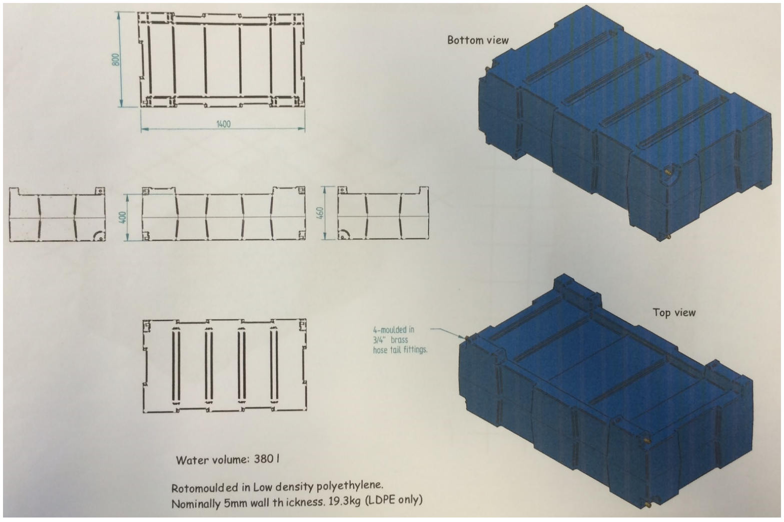


FIGURE 4.8: Initial In-Slab Water Tank Design

The tank was to be Rotomoulded in Low Density Polyethylene with a nominal thickness of 5mm, a dry weight of 19.3kg and an internal volume of 380L. The tanks would be filled through two brass fittings and the top of the tank and emptied with two brass fitting at the bottom of the tank. Appropriate plumbing will be cast in to the foundation to fill and empty the tanks.

To reduce heat losses in the foundation the beams and water tanks need to be insulated from the prepared site. Conqueror Ltd offer a 100mm thick PIR (Polyisocyanates) foam board that has a good insulation coefficient (R4.8) as well as excellent compressive strength and load spreading ability. This board will cover the entire footprint of the foundation to form a high performing thermal break.

The aim of the first foundation design was to fit as many water tanks as possible to reduce the weight of the required concrete. The foundation is also required to be transportable so the beam structure must also be capable of spanning between lift points with minimal deflection. Figure 4.9 shows a Plan view of the first foundation design. This foundation plan includes 18 water tanks for a total water volume of 6840L. The beams are 200mm wide with a 200mm perimeter and an 85mm topping slab. The total concrete mass including the tilt slab walls was calculated to be 27,000kg.

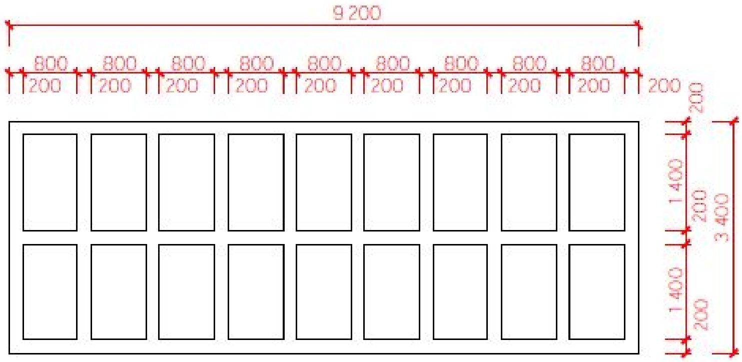


Figure 4.9: Initial Foundation Beam and Tank Plan

4.2.4 Final Foundation Design

The foundation underwent multiple revisions throughout the design process. The foundation design in the initial concept was identified to contain excessive mass. This excessive mass was largely attributed to the number of tanks used in the design. Using multiple small tanks increased the number of concrete beams included in the design, making for an overweight foundation. Although it was identified that the foundation could still be transported, the cost of lifting and transportation increases with an increase in the required capacity. The tilt slab walls were removed as calculations showed that they did not offer a substantial increase in thermal performance and their weight was having a detrimental effect on the transportability of the structure.

The changes in foundation layout necessitated finding new water tanks that could be more effectively cast within the slab to minimize excess concrete weight. Appendix C shows all of the different foundation layouts and water tank designs as the foundation was refined. The final design incorporates four large tanks that are larger in area but lower in height. This design does affect a decrease in water storage but also significantly decreases the weight of the foundation to 11,500kg. The new tanks are an existing product from ThinTanks Ltd and are readily available. The 1000L model was chosen due to its low, 260mm, profile. Figure 4.10 shows the chosen water tank model.

The final foundation design includes four of the ThinTanks for a total water volume of 4000L. This volume is a significant decrease compared to the initial design but the overall benefit of lower weight far exceeds the downfall of having less dynamic thermal mass and water storage. The layout has a 400mm perimeter beam with only three 400mm internal beams. The beams are reinforced by HD12 reinforcing bar and will be poured with a

FIGURE 4.10: 1000L Polyethylene Thin Tank

fibrous concrete to aid in flexibility when transported. The final foundation design has an estimated overall mass of 12,050kg including the water tanks. Figures 4.11 and 4.12 show a plan view of the final foundation layout and drawings of the beam cross sections respectively including detail of the reinforcing bar placement.

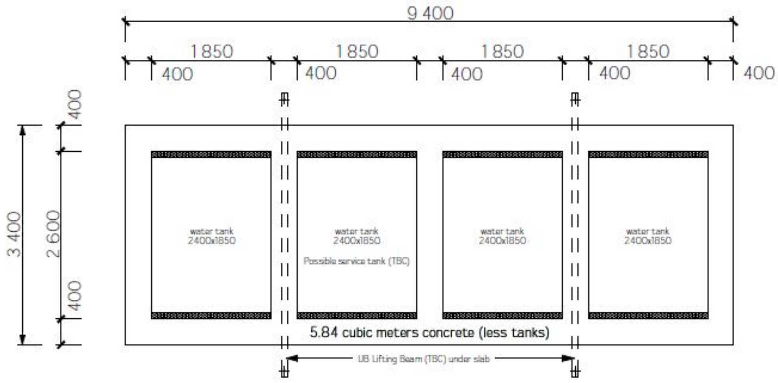


FIGURE 4.11: Final Foundation Beam and Tank Plan

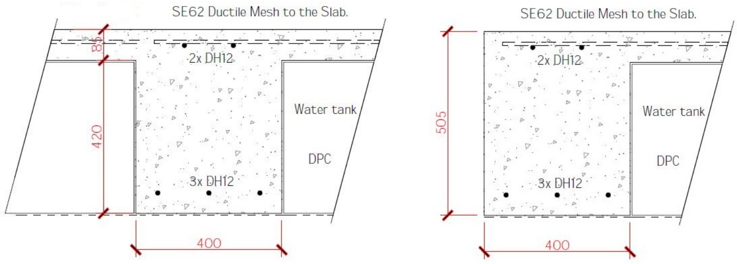


FIGURE 4.12: Final Slab Rib and Edge Beam Details

4.3 Structural Insulated Panels

4.3.1 Conqueror International

Conqueror International were identified at the commencement of this project as being a potential project partner. Their main product, PIR Structural Insulated Panels, are an excellent match to the thermal performance and fast build requirements of the project. The panels in question are made in Christchurch and Conqueror can offer competitive pricing and lead times. Figure 4.13 shows the primary construction of the panels.

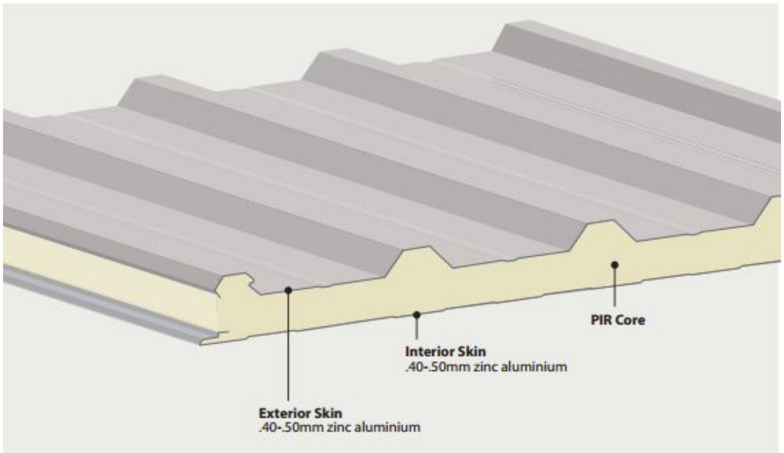


FIGURE 4.13: Conqueror PIR Panel Construction

The core material of these panels, Polyisocyanates (PIR), is a thermosetting plastic that is combined with a blowing agent to produce a foam with an extremely high thermal coefficient. The foam also has a very high compressive strength and is fire rated. The foam is sandwiched between two thin layers of zinc aluminium coated steel. The result panel is very rigid and is capable of spanning large distances unsupported. Table 4.1 shows a comparison of the rated R values for the different core thickness's or various core technologies where EPS is Expanded Polystyrene, XLAM is Cross-laminated Timber, and MW is Mineral Wool . Table 4.2 shows the spanning ability of the ISJ Roof panels with different thickness's

Table 4.1: R Values of Insulation Materials with Different Thickness's

	EPS	XLAM	**PIR**	MW
50mm	1.2	1.61	**2.4**	1.2
75mm	1.8	2.42	**3.6**	1.83
100mm	2.4	3.22	**4.8**	2.44
150mm	3.6	4.84	**7.1**	3.66

Table 4.2: Spanning Distance of Conqueror Panels with Different Thickness's

Thickness	**Maximum Span**
50mm	3.0m
75mm	4.25m
100mm	5.0m

As the panels are primarily designed as a façade panel system, a proprietary framing and fastening system would need to be created. Typically the panels are fixed to a rigid, industrial framing system that is exposed on the interior of the building. As this application is residential, exposed structural members are not acceptable for aesthetic and functional reasons. A system needed to be produced that had minimal impact to the interior of the building while still being structurally sound.

Appendix C shows the complete initial design as modelled by the drafting team and Stonewood homes. This system assumes the panel's ability to not only provide bracing support to the structure, but to also provide the required vertical and horizontal strength required to support all possible loads. The steel profiles in the system primarily provide a means of fastening the panels at all except butt junctions, where Conqueror's own fastening system takes over. Figure 4.14 shows the proprietary fastening system used by Conqueror Ltd.

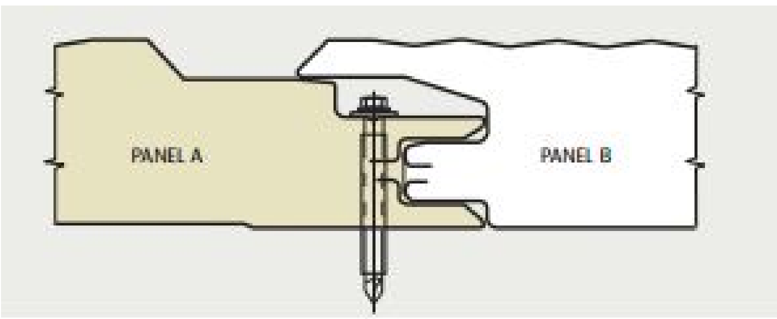


Figure 4.14: Conqueror PIR Panel Fastening System

This initial concept largely satisfied the technical requirements of the design but the aesthetic requirements were not met. After seeking advice on the aesthetic of the design it was concluded that the steel interior of the Conqueror Panels would not be acceptable for the purposes of a residential build. Traditional interior coverings were considered such as fixing Gib board to the interior, but this method was not deemed acceptable practice by Conqueror International and would have voided the product warranty. An entirely different Structural Insulated Panel System was required to satisfy the need for a traditional interior finish while still maintaining a similar level of thermal performance and ease of construction.

4.3.2 VersiPanel

There are various Structural Insulated Panels on the market that would satisfy the thermal performance requirements of the building, but few that provide a means of simple structural design. The final building design utilizes a product from an Australian company, VersiClad Ltd, in particular their VersiPanel Product. VersiPanel has a Polystyrene core with either Fibre Cement or Oriented Strand Board skins. The key feature of the VersiPanel system is the fact that its core is 91mm wide allowing standard 90x45mm framing timber to be wedged between the two skins of the panel. This system makes for the entire building framework being enclosed by the panels and only requires studs at 1200mm centres as opposed to the current building standard of 600mm. Figure 4.15 shows the general assembly layout of the Versipanel System.

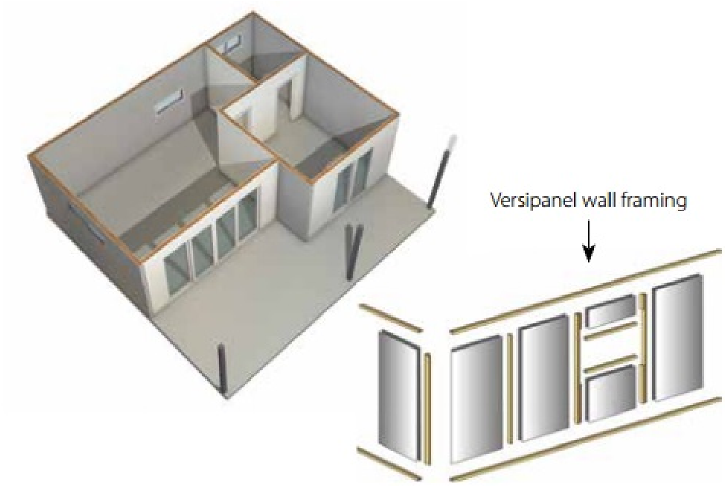


FIGURE 4.15: Versipanel SIP System Assembly

Using VersiPanel's with Fibre Cement interior skins also solve the problem of interior aesthetics as the Fibre Cement with plastered seams is very similar in look and feel to Gib Plaster Board lining. The exterior of the panel can either be Fibre Cement with plastered seam under paint or Oriented Strand Board with a direct fix cladding for weather protection. A notable downside of the Versipanel system is the lower base insulation coefficient of R2.4 vs R4.8 when compared to the 100mm thick Conqueror Panel system.

4.4 Superstructure Design

4.4.1 Framing Plan

The VersiPanel framing system uses a very elegant system for installing traditional 90x45mm timber framing. The internal dimension between the skins of the sandwich panel is 91mm, resulting in a snug fit for a timber stud. Figure 4.16 shows section views of a single and double stud panel connections.

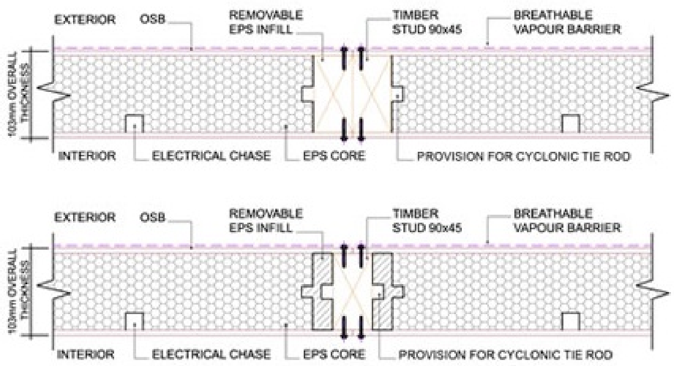


Figure 4.16: Section Views of Versipanel Internal Framing

The EPS on all four sides of the panels is hollowed out at the factory to accommodate the double stud configuration. A removable EPS infill is provided that can be inserted when the single stud configuration is used. When panels are cut to custom sizes the EPS in the sides of the panels has to be hollowed out with a specialized hot knife cutter to ensure the timber studs fit correctly.

All openings require a double stud each side to support the head and sill beams. The outer studs run the full height of the wall while the inner studs run to the over and undersides of the head and sill respectively. This design creates a complete frame around the windows or door and creates a strong lintel beam above the opening to support all load applied by the roof. Figure 4.17 shows an exploded assembly view of a window opening.

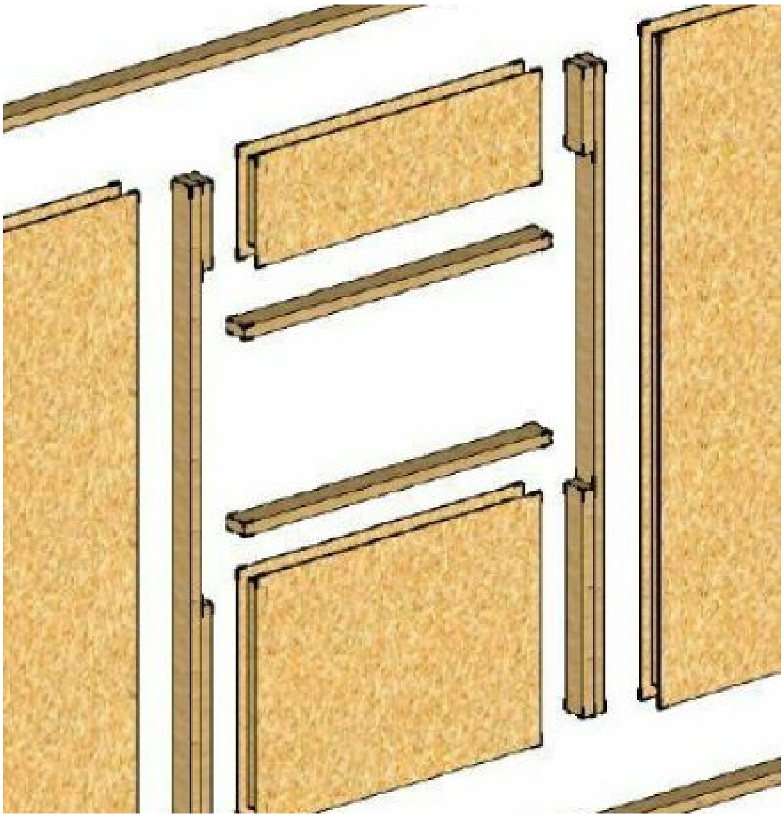


FIGURE 4.17: VersiPanel Framing with Window Opening

To use the VersiPanel system efficiently, the framing plan should meet the following guidelines:

- Wall lengths of 1200 & 900mm wide modules
- Wall heights of 2400, 2700, 3000 or 3600mm (3600mm in FC/FC only)
- Window widths in 900 & 1200mm modules: 900, 1200, 1800, 2100, 2400mm, etc.
- Maximum window/door opening of 2400mm without requiring additional engineering for lintel beam

The window widths in the design are all 1800mm and the single door opening is 2400mm. As the building has to meet size requirements for transportation, the ideal building width cannot be achieved. Hence, panels on the ends of the building will need to be cut to custom widths. The rear of the building achieves the lengths to accommodate eight 1200mm wide panels while the front is made up of three 1200mm panels and two custom cut panels. Figure 4.18 shows the plan view of the building with the Versipanel stud layout marked.

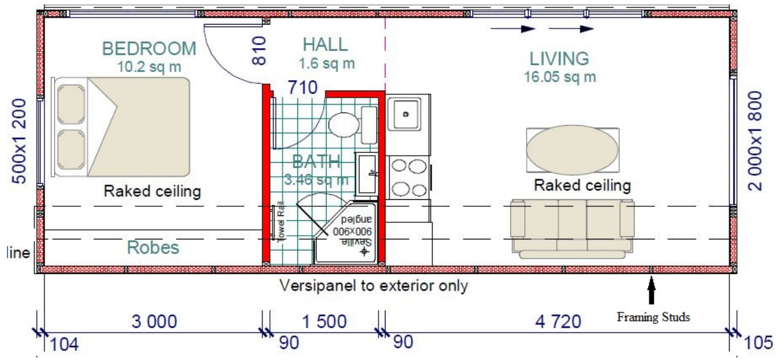


Figure 4.18: VersiPanel Stud Layout

The bottom plate of the framing will be bolted to a steel angle member that runs around the perimeter of the Foundation slab. This plate extends the panels 100mm out from the foundation to provide a gap under the main panels to fasten insulating panels around the perimeter of the slab. Figure 4.19 shows a section view of the bottom plate and steel angle.

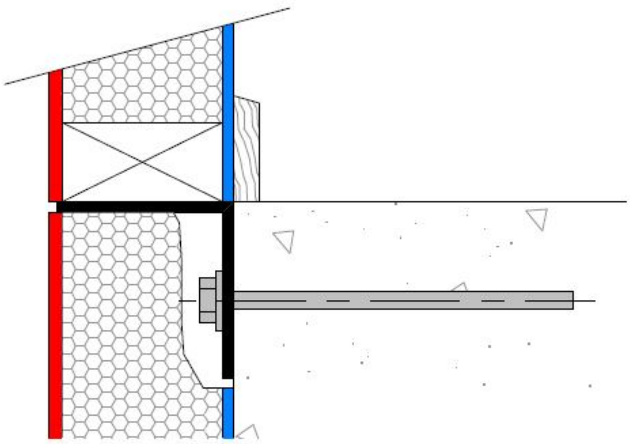


Figure 4.19: Framing Bottom Plate and Supporting Steel Angle

The walls of the bathroom are not required to be insulated and so VersiPanel is not used in this area to save on costs. The walls will be traditionally framed and lined with Gib board providing a convenient cavity to run services. These walls will also be load bearing, supporting the center section of the roof. The main walls will be gable framed as this method is the most cost effective technique, negating the need for a separate roof truss. Figure 4.20 shows a side elevation of one of the gable framed walls.

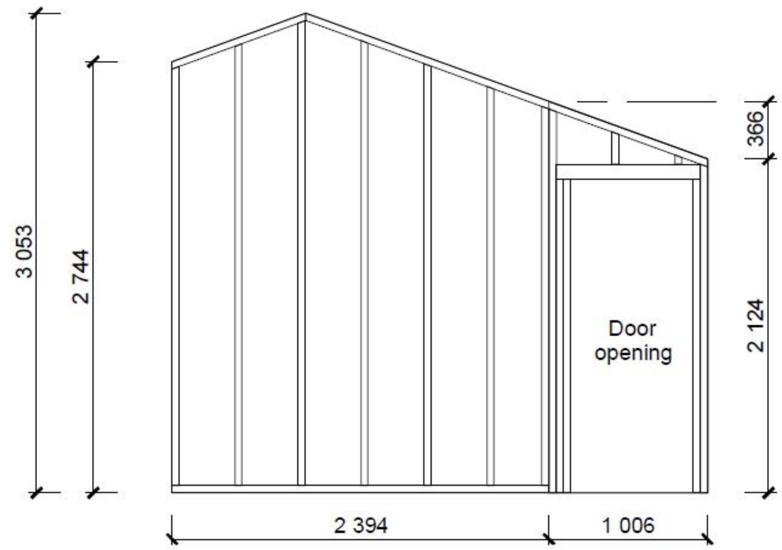


FIGURE 4.20: Gable Framed Inner Wall

To meet the 4m height restriction, the North facing wall of the building was brought down to the height of the sliding door. This reduction in height meant that there was no room above the door to provide a sufficiently strong timber and fiber cement lintel beam to support the roof load. The decision was made to replace the North wall top plate with a section of 89x89x3mm Galvanized steel SHS (Square Hollow Section). The steel ensures a sufficiently strong lintel beam while still fitting in between the skins of the VersiPanel wall, preserving the aesthetics of the North wall. Figure 4.21 shows a detail of the SHS steel top plate.

4.4.2 Roof Type

The Conqueror panel system did not meet the aesthetic requirements for the walls of the building, but it was deemed acceptable for the roof of the building as the painted steel interior finish is acceptable on the ceiling. The Conqueror panels have a very large spanning ability which results is a very simple roof design.

One of the primary design considerations for the roof is the integration of PV panels as the pitch of the roof has a significant effect on their output. This effect will be further detailed and analyzed in Chapter 6. For the most consistent year round electricity production, the latitude of the PV panel's position should be implemented as the angle

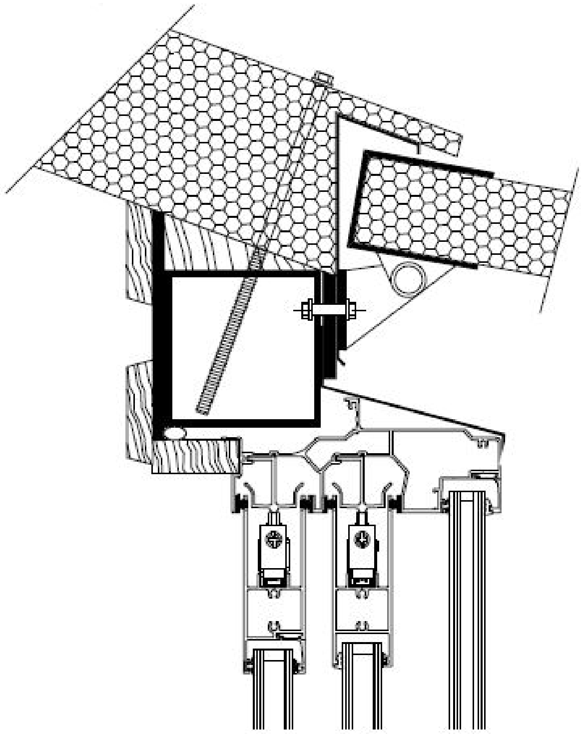


FIGURE 4.21: SHS Steel Top Plate Detail

of the panel with reference to the horizontal. For the case of Christchurch, New Zealand, the ideal fixed PV panel angle would be 43.5 degrees. Figure 4.22 shows the daily solar incidence angles for differing times of the year in Christchurch.

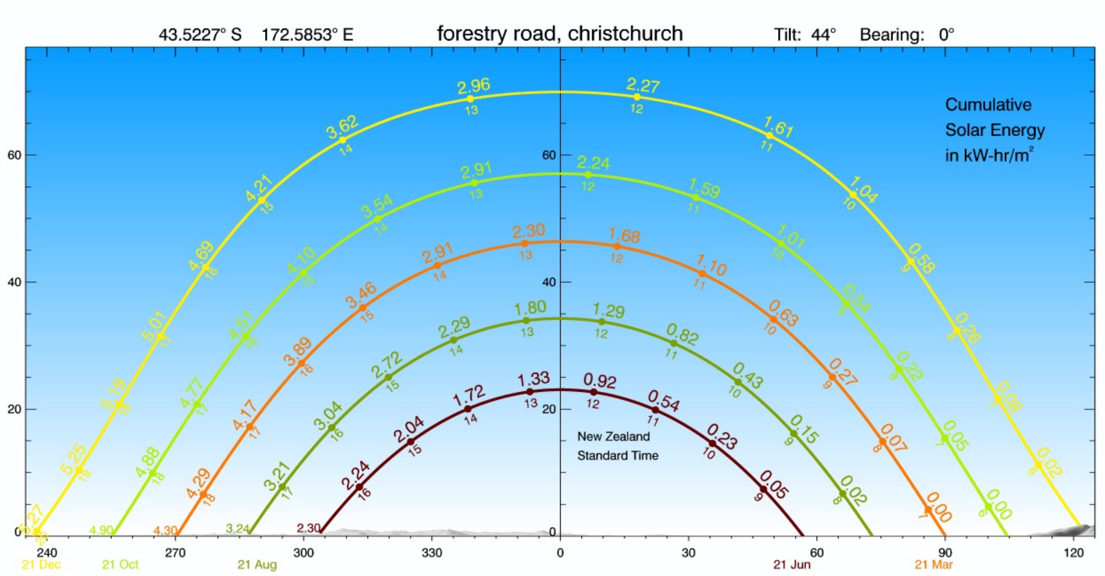


FIGURE 4.22: Solar Angles by Month with Cumulative Solar Energy

An angle of 43.5 degrees would make for an excessively tall building with unsatisfying aesthetics, therefore the initial building concept included an uneven gable roof with a

30 degree angle. This angle introduces a small loss in winter energy production but significantly reduces the profile of the building when compared with 43.5 degrees. The north-facing side of the roof is designed to provide maximum area for PV Solar Panel installation as well as providing an acceptable pitch for year round energy harvesting. Figure 4.23 shows a section view of the initial roof design. All iterations of the roof design can be seen in Appendix C in the concept drawings history.

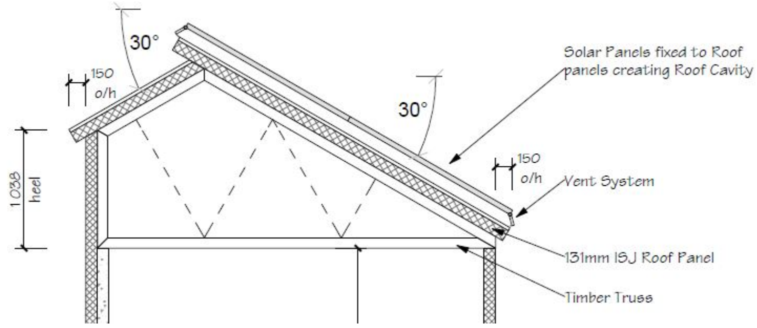


FIGURE 4.23: Section View of the Initial Roof Design at 30°

Another limitation with pitch is the height limit for a transportable building. The working limit for the height of the building is set at 4m. The above design did not achieve this height goal with an overall height of 4900mm. Exceeding the allowed 4m would result in the requirement of Land Transport Permits, drastically increasing the cost of transporting a finished product.

The final concept has a roof pitch of 20 degrees which is significantly less than the optimal angle. However, the resulting solar energy gains will still be sufficient for this application and is fully justified in Chapter 6. The low roof angle teamed with the low profile of the final foundation design, reduced the overall height of the building to an acceptable level of 3739mm. Figure 4.24 shows the final roof design. A 180x45mm timber beam is positioned along the ridge of the roof to support the upper side of the spanning roof panels. The beam will be supported by double studs on the East and West walls, as well as doubles studs at the head of the gable framed interior walls. Figure 4.25 shows the beam detail.

4.4.3 Weather Tightness

The E2 External Moisture Standard was the point of reference in the design of the building's junction details. This standard was used to guarantee a pass result in the

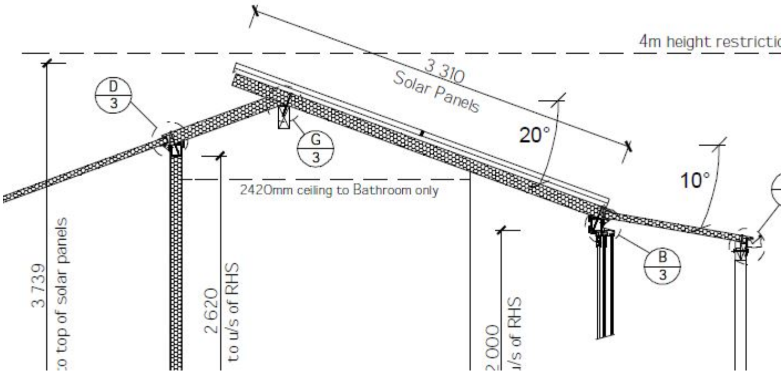


FIGURE 4.24: Section View of the Final Roof Design at 20°

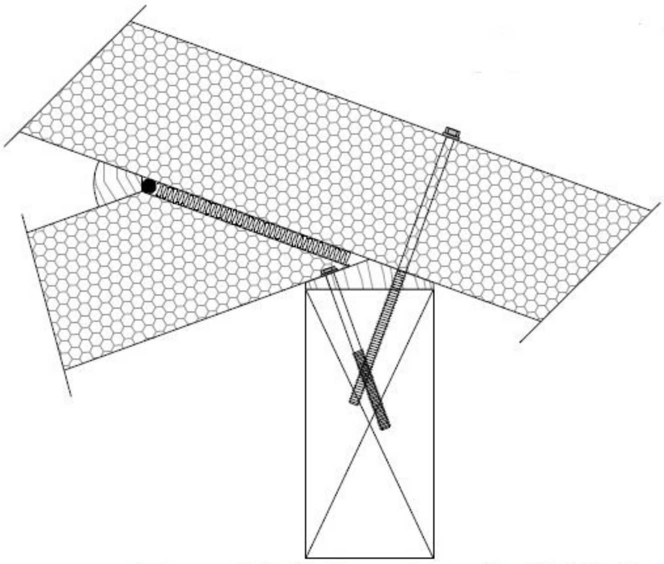


FIGURE 4.25: Section View of the Structural Roof Beam

weather tightness section of a building consent. This building design has seven key junction details that are required to be weather tight.

The E2 Standard includes a building technique that is very similar to that of VersiPanel. It outlines the technique as having a typical insulation filled cavity wall with fibre cement sheets as the outer skins. This technique almost directly mimics the insulation and outer skins of the VersiPanel system. Figure 4.26 shows the section details provided in the E2 Standard of a Head and Sill. The details for the building design have been drawn to be as close as possible to the standard of figure 4.26. Appendix C shows all of the building junction details as well as a Jamb detail taken from the E2 Standard.

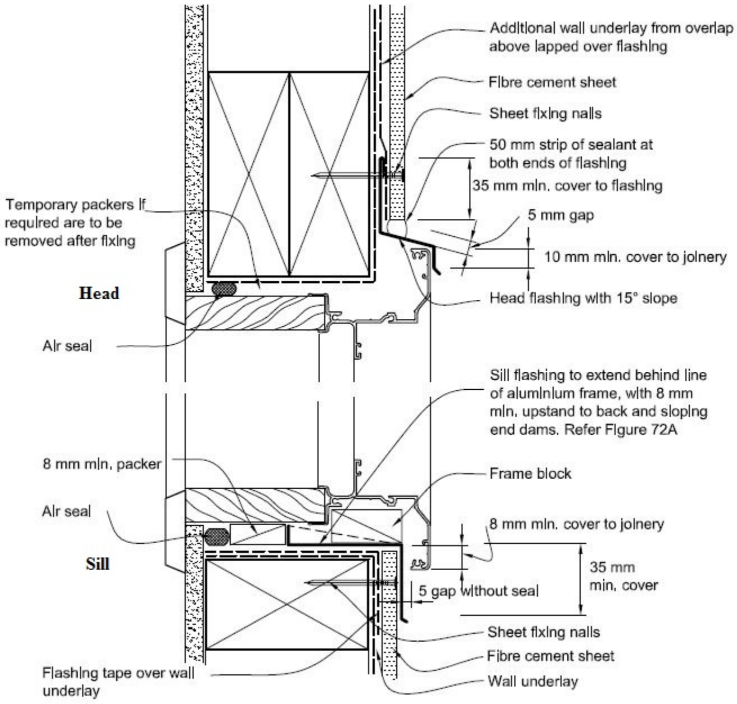


Figure 4.26: Head and Sill Deatails from the E2 External Moisture Standard

4.4.4 SolarPanel Integration

Dennis Chapman has provided a solar panel mounting system that he has had manufactured and thus proven. The solar panels have an extruded aluminium alloy frame that has been designed with clip-in mounting rails and weather-proofing surfaces. All clip-in parts are sealed with rubber profiles. This mounting system provides a relatively air tight void beneath the solar panels which will be utilized as a thermal duct. Figure 4.27 shows a profile of the side mounting bracket for the solar panels.

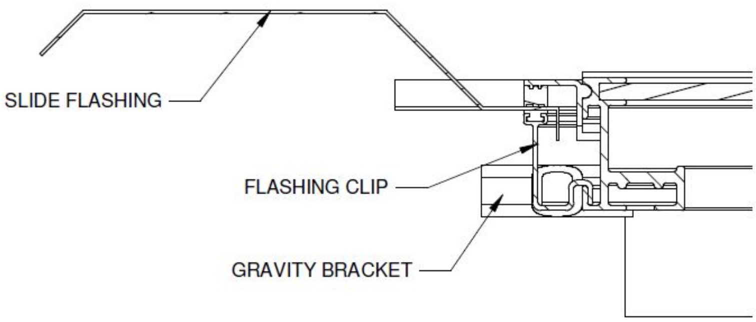


Figure 4.27: Profile View of Solar Panel Fastening Hardware and Flashing

As the panel mounting system is fully sealed, Dennis Chapman was able to successfully pass the system through the Canterbury Council building consent process as a primary weather tight building envelope. This mounting system gives excellent flexibility in the design of a BIPV/T system using these panels. For the purpose of this design, the roof will already be weather tight with the use of Conqueror panels so will be considered the primary weather-tight barrier.

To maximize the thermal energy collected from the back of the solar panels, the channel height of the thermal duct needs to be considered. A large channel height will provide a low back pressure to the circulating fans but increase the required building materials and reduce turbulence of the airflow, reducing harvested energy. A small channel height will be restrictive and require powerful fans for circulate air but will reduce building materials and increase turbulence, increasing harvested energy. Dennis Chapman's Eco-Castle uses a 150mm duct which has been proven to provide an acceptable thermal energy gain. As the roof panels in this design have large profiled ribs on the top surface, the required spacing between the solar panel brackets and the roof panel will be minimal. It was decided that 45x45mm timber batons would be used as spacers as they are low cost and readily available. Figure 4.28 shows a side section of the mounted solar panels.

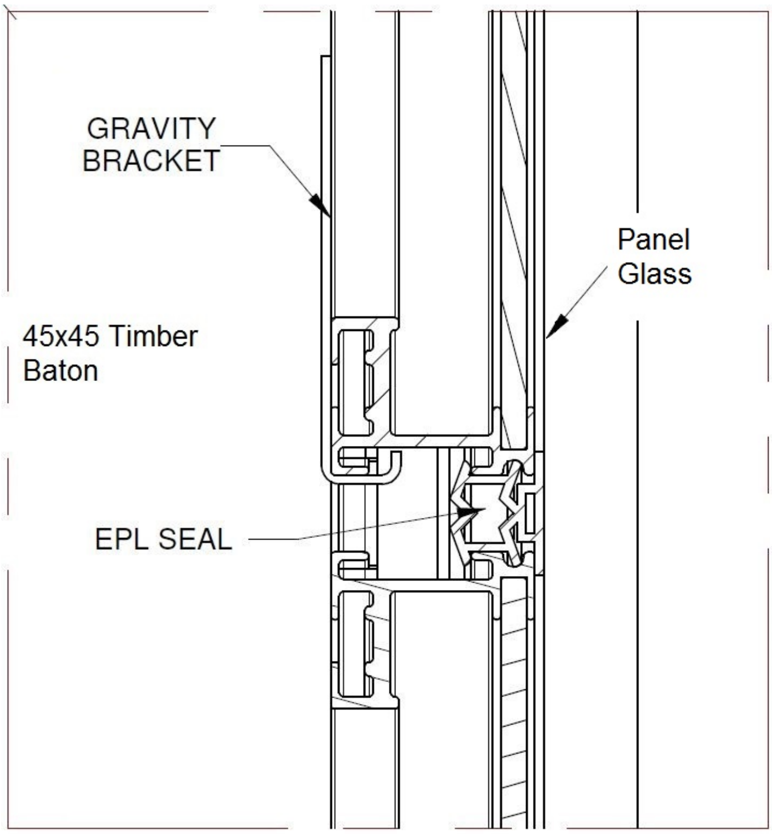


Figure 4.28: Side View of Solar Panel Fastening Hardware

Figure 4.27 also shows a profile view of the side flashings that seal the sides of the thermal duct. The flashings are sealed to the PV Panel Aluminium extrusions and sealed to the side of the building with silicone sealant and mechanical fasteners. Complete sealing of this flashing is essential in reducing thermal losses in the duct.

The effective flow under each panel is 0.55m^2. This value equates to a simple duct height of 100mm, providing a good balance between flow velocity and back pressure.

4.4.5 Awning and Carport Design

Since the building is being designed to be transportable, the awning and carport must be removable for the building to be within the maximum transportable width of 3.6m. The company Conqueror manufacture a 50mm ribbed SIP at a relatively low cost that would provide high strength and stiffness while eliminating the need for bracing. The panels are of the same construction as the roof panels, which are to be used in the main superstructure, so have a high insulation coefficient that will not be utilised in this application. Therefore, these panels could be interpreted as an over specified building material, but the ease of construction and aesthetic appeal justify their use.

The awning and carport will comprise sections of the Conqueror panel with an exterior steel 'C' channel frame. The top of the frames will mount to the front and rear of the building superstructure on semi-permanent hinged brackets and will be supported and the bottom end of the frame with concrete anchored timber posts designed to accommodate the required wind lift loads. Figure 4.21 shows a section view of the awning connected to the building's top plate via hinges welded to the awning 'C' channel frame and the top plate. This design allows for a relatively low weight detachable shelter that is aesthetically suited to the rest of the superstructure.

The angle and height of the awning can have a significant effect on the incident solar radiation through the front glazing of the building. While the awning is designed to have a fixed angle, this angle could be changed to account for the building's geographic location. Figure 4.29 shows a profile view of the awning as drafted with an overlay of solar radiation angles.

The angle, height and length of the above awning provides good shelter from solar radiation during high summer sun angles while remaining open to solar radiation from lower

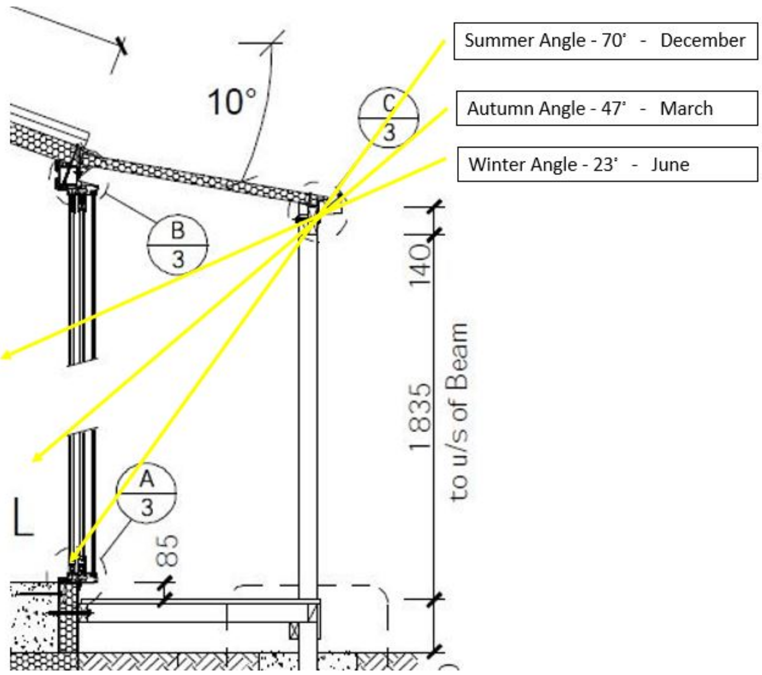


FIGURE 4.29: Profile View of Awning with Varying Solar Angles

winter sun angles. 70 degrees is the highest solar radiation angle that will introduce radiation through the North facing glazing of the building. In Christchurch, New Zealand, between the dates of approximately February 5 and November 25 there will always be a measurable amount of incident solar radiation through the North facing glazing in the hours of daylight.

4.4.6 Insulation Coefficient Study

The Versipanel system has a rated insulation value of R2.4. This rating pertains only to the panel itself and does not include studs and fastening junctions that are associated with a building. These junctions need to be analysed in order to find the average insulation value of the overall wall system. Figure 4.30 shows a section view of a vertical panel join with indicative R values overlaid.

R values of the building materials are taken from NZS4214:2006 and manufacturer data sheets and used to calculate the average R value of the entire exterior envelope [9]. Table 4.3 shows the calculated R values of all material types used in the design.

Using these R values, each junction in the building can be analysed to calculate its average sectional R value. These values are then collated to calculate the average building

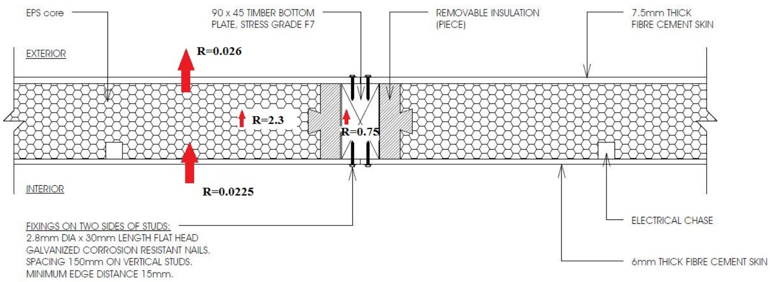


Figure 4.30: Section View of a Vertical VersiPanel Join

envelope R value. The average R value of the building was calculated to be R1.82 with a total conducting area of 128.5m^2. The calculated thermal energy loss of the building was 70.7W°C^{-1}. Further analysis of the resulting thermal performance of the building will be undertaken in Chapter 6.

4.4.7 3D Modelled Concept

The primary purpose of 3D modelling is to provide a detailed view of the outer dimensions and to get closer to a real world view of the building. As the end goal of this project is a saleable product, the aesthetic appeal of the building is crucial element for its success.

Figure 4.31 shows the first 3D modelled concept. The overall technical requirements were met, but the aesthetic appeal of the building is not up to Stonewood's standards. The design provided a base to begin technical and aesthetic refinement. The most notable change incurred after this initial 3D model was created was the reduction in roof pitch. Appendix C shows all 3D modelled concept figures from throughout the project.

Table 4.3: R Values of Construction Materials

Material	Thickness (mm)	R Value
Pinus Radiata	90	0.78
Versipanel	106	2.4
Conqueror Panel	100	4.8
Fibre Cement Board	7	0.03
Steel	100	0.002
Concrete	345	0.22
Concrete	85	0.05
Low-E Double Glazing	14	0.4

FIGURE 4.31: First 3D Modelled Concept

FIGURE 4.32: Final Rendered 3D Modelled Concept

Figure 4.32 shows the rendered final concept model. All aesthetic requirements have been met with Stonewood Homes being satisfied that the overall look of the building qualifies as a saleable product. The intended market for this design is Off-Grid Self-Contained Transportable buildings. This market could include applications such as remote farm quarters' or holiday homes.

Chapter 5

Electrical & Systems Design

5.1 Off-Grid Power Systems

This building design requires a complete Off-Grid option to qualify as a standalone building solution. The system will largely be designed with the use of popular off-the-shelf units to ensure repeatability and consistency of performance should the building become a mass produced item. The aim to create a cost effective Off-Grid system that is capable of supplying the Electrical needs for one inhabitant indefinitely. To calculate the storage and generation required, generalized data has to be analysed to gain an understanding of typical Electricity usage habits.

5.1.1 Load Estimation

To size an off-grid power system correctly it is essential to analyse typical inhabitant behaviours and study the statistics of typical residential load data. A well sized system will not only be capable of supplying the average projected load but will also provide a constant supply in extended periods of low generation. In general, in the Canterbury region, residential loads increase substantially in the winter season due to the increase in space and hot water heating requirements while solar resources are significantly diminished. This worst case scenario will be the design point for the off-grid system to ensure reliable year-round operation.

Table 5.1: Approximate maximum load, time used per day, and subsequent daily consumption of electrical appliances

Appliance	Max Load (W)	Time Used Per Day (h)	Daily Consumption (KWh)
Microwave Oven	900	0.25	0.225
Kettle	2000	0.2	0.4
Toaster	800	0.2	0.16
Washing Machine	700	0.5	0.35
Vacuum Cleaner	1000	0.1	0.1
Fridge/Freezer	300	1	0.3
Water Pump	200	0.5	0.1
LED Lighting	150W	4	0.6
Laptop Computer	60	1	0.06
TV 32”	70	3	0.21
Stereo System	30	4	0.12
Ventilation System	100	12	1.2

In off-grid applications, appliances and services will be tailored to minimize the required electrical energy. For example, a gas hot water heater will be installed as well as a gas stove, as these are two major users of electrical energy in a residential buildings. Electrical loads need to be analysed individually to gain a good approximation of the projected load. Table 5.1 shows all of the expected appliances and services and their respective approximate maximum load, time used per day, and subsequent daily consumption.

Historical residential load data has been procured from BRANZ [3]. This data includes typical residential electricity loads per person as well as a breakdown of what appliances and services makes up the total load. The data can be broken down in to individual appliance statistics and then applied to the above building specific maximum loadings to provide a projected daily average load. Figure 5.1 shows the monthly proportion of energy usage in a standard New Zealand household.

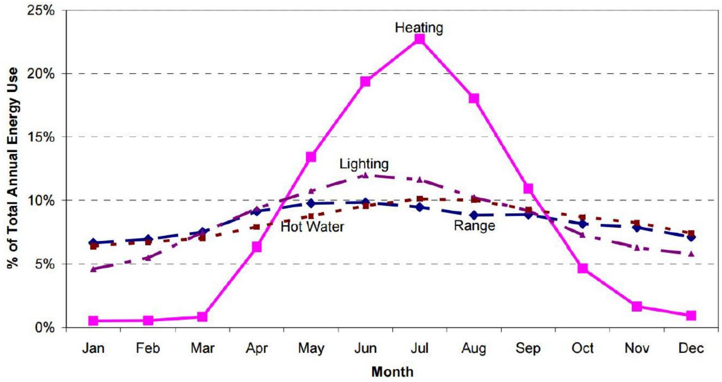


Figure 5.1: Average NZ household monthly load percentages [3]

One of the specifications of this system is that it should be entirely stand-alone, supplying 100% of the building load. While this specification is achievable, it is impossible to accurately predict the usage habits of any inhabitant and thus there is the potential for over loading of the buildings supply and subsequent energy shortage.

5.1.2 Generation Capacity

The primary electrical energy source for the building will be via 250W PV panels. The generation capacity of the building is fixed for a given design roof area as it limits the maximum possible PV panels that can be installed. The primary one-bedroom floor plan has sufficient roof area for 18 250W PV panels providing a total maximum output of 4500W. Appendix A shows the data sheet of the PV panels supplied by Dennis Chapman.

The PV panels are installed at a tilt angle of 20 degrees which is close to the ideal angle in summer (Canterbury, NZ), but will provide significantly lower output in the winter months when the ideal angle is between 55-70 degrees. Data was taken from the solar rig and historical NIWA data to predict the daily average generation over a year. Figure 5.2 shows the projected monthly generation over a year in Christchurch.

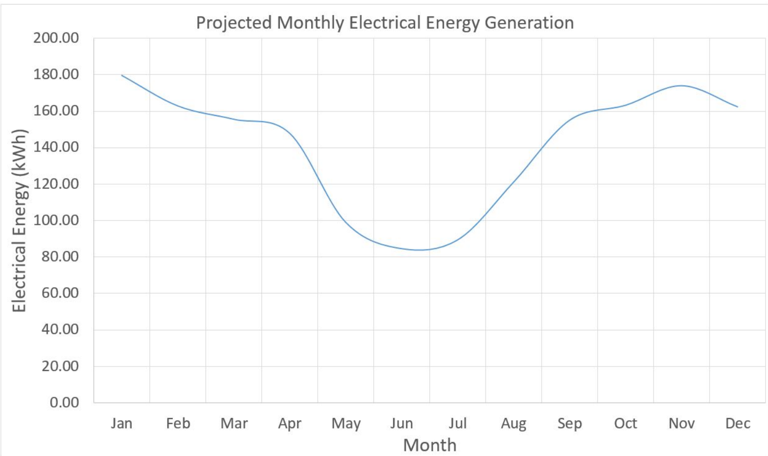


FIGURE 5.2: Projected Monthly Electrical Energy Generation Over the Period of a Year

5.1.3 Energy Storage System

Electrical energy storage will be achieved with a lead-acid or lithium-ion battery bank. The objective of the supply is to cover the electrical load of the building when it is not able to be met by generation. These times include night time hours as well as extended periods of adverse weather conditions.

The main advantages of lithium-ion batteries is their low weight to capacity ratio and high current density. The choice between lead-acid and lithium-ion battery banks will be driven solely by cost as the overall weight of the bank is insignificant in the context of a building and the maximum electrical current is relatively low. Comparing the cost of similar capacity banks of the two chemistries is not straight forward as there are considerations that need to be made for the maximum discharge of the cells.

Lead-Acid batteries have very limited life spans when compared to other battery chemistries with the depth of discharge being a major factor in their rated cycle lives. Typical commercial rated Lead-Acid Deep Cycle batteries such as the Crown CR430 exhibit drastically reduced cycle life when the depth of discharge is more than 50%. The Crown Battery Manufacturing Company advertises that the CR430 battery will perform 1200 Cycles at a depth of discharge of 50% and 3000 Cycles at a depth of discharge of 20% [10]. However, if long battery life is valued, the capacity will be significantly less than the advertised capacity, which drastically affects the cost effectiveness of the chemistry.

Although lithium-ion batteries are significantly more expensive than lead-acid for an advertised capacity, they have a number of advantages. It is considered safe to discharge this chemistry to a significantly lower state of charge, giving them a significantly better actual to advertised capacity ratio when compared with lead-acid. Lithium-ion batteries also have a significantly higher cycle life. For example, the Winston Battery is capable of 5000 cycles when taken to 80% Depth of Discharge.

Lithium-ion battery banks have a number of advantages, but they are still more expensive for a required effective capacity. Appendix B shows a lifetime cost comparison between readily available lead-acid and lithium-ion battery banks. The required capacity of the battery bank will be further detailed and analysed in Chapter 6.

5.1.4 Backup and Auxiliary Generation

Solar energy can at times be very inconsistent making it difficult to design a reliable, continuous electrical energy system with solar as the sole source. The power system in this project is designed to be an indefinite power source, but this requirement can only be true if there is design energy usage limit. The energy usage limit pertains to a 'normal' one person residence with an amount of extra capacity to ensure reliability.

Auxiliary renewable energy generation sources can be used to supplement solar generation during times of low solar resources. Wind and Hydro turbines can provide a good source of auxiliary power depending on the building site location but are also inconsistent energy sources. By far the easiest to implement would be a small roof mounted wind turbine. Depending on the location of the building site, this option could provide the necessary system reliability.

In the case that solar generation is not sufficient to cover the usage of the inhabitant and auxiliary generation is not installed, backup generation will be required to eliminate system stability and reliability issues. The most common on-call backup generation comes in the form of petrol or diesel powered rotary generators. A backup generator would need to be sized accordingly to the inhabitant's energy usage habits to ensure consistent supply. The backup generator could be incorporated in the overall building control system and would only be run when the battery bank became noticeably depleted.

Detailed backup and auxiliary generation system designs will not be included in this thesis as the systems would be designed and produced on a case-by-case basis to the specific requirements of the end-user.

5.2 Grid-Tied Power Systems

This project is primarily designed around an off-grid application, however it could also be designed as an energy positive Grid-Tied building. As the building design has a large area of PV panels, midday peak production will be significantly larger than the system load causing a large energy surplus. To avoid back feeding the electricity network and to capitalize on the available energy, a load shifting system will be required. Figure 5.3 shows a diagram of a load shifting, grid-tied energy system.

5.2.1 Grid-Tied Inverter

Stonewood homes Ltd currently offers a Solar Electricity system with all new builds, known as the Solar Ready Home. This product consists of a compulsory Solar Ready

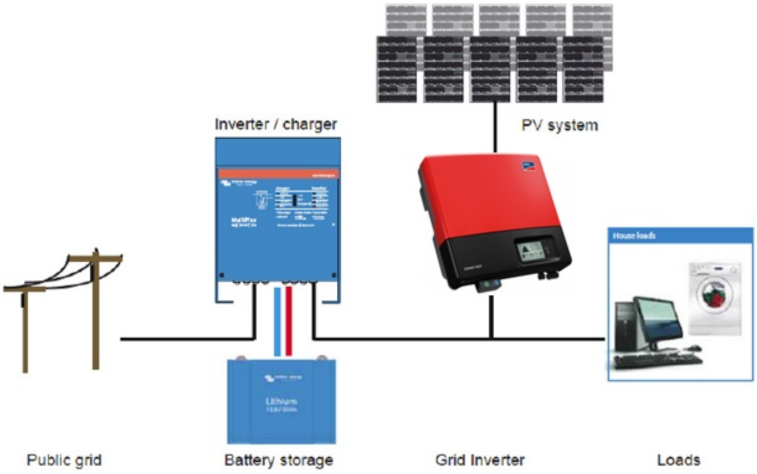


FIGURE 5.3: Load Shifting Grid Tied Solar Electricity System [11]

Box and optional Solar panel installation. At the heart of the Solar Ready Box is an Enasolar Grid Tied Inverter sized appropriately for the application. In all Stonewood builds this Box is installed to ensure seamless integration should the customer choose to opt for the Solar Panel Package.

If the designed building in this project was to be built and connected to the Grid, a 4.0kW Enasolar Grid Tied Inverter would satisfy the requirements of the integrated Solar System. The inverter can handle up to 4.5kW peak input power at an efficiency of 90%. Appendix E shows the full specification sheet for the 4.0kW inverter.

5.2.2 Load Shifting

The most common way New Zealanders purchase Electricity is through an Electricity retailer. These retailers purchase energy on the Spot Market from generators around New Zealand with the spot price of wholesale electricity varying widely throughout the day as demand rises and falls. Instead of end users being exposed to volatile price changes, the majority of retailers offer customers a fixed, per kWh charge. This approach is in some ways beneficial to the consumer by protecting end users from volatile pricing spikes, but it also limits their ability to take control of their energy usage and to benefit from very low overnight and midday energy prices.

At the beginning of 2015, a new energy retailer, Flick Energy, entered the market offering a pricing plan to end users that follows the price of the Electricity Spot Market. Simple load management can be used to benefit from the scheme but the greatest savings are realized with active load shifting.

A load shifting battery bank is an energy storage device that is capable of supplying a building's full electrical load for a period of time long enough to avoid purchasing energy from the grid at times of peak demand. The battery bank can then be recharged from alternative energy sources or from the grid at times of low demand. This strategy has immediate financial benefits as well as helping to stabilize the larger grid network and decrease price volatility.

In the context of this project, the biggest advantage is the ability to charge the batteries during the day using solar resources. The energy gained during the day can then be used throughout the evening. While some energy retailers do accept back feeding with bi-directional meters, the remuneration rate is often significantly lower than typical energy rates. Therefore the PV system is underutilised resulting in a significant decrease in the system's payback period. Using the energy from PV panels to charge a load shifting battery bank can eliminate an oversupply condition in which the PV panels would be forced to feed energy in to the grid.

As solar resources can be variable and unpredictable, an active charging system has to be designed that has the capability of predicting future loads and solar resources to ensure the battery bank has sufficient capacity to fully capitalize on the available energy. Figure 5.4 shows a flow diagram of a simplified algorithm for control of the load shifting system.

5.3 BIPV/T and Ventilation Systems

The BIPV/T system provides the primary active heat energy source for the building, and the incident solar radiation through the North facing windows is the primary passive heat energy gain method. While the system will have inherent limitations, it will be capable of actively controlling the interior air temperature when the outside ambient temperature is less than the target interior temperature of 20°C and sufficient solar resources are available.

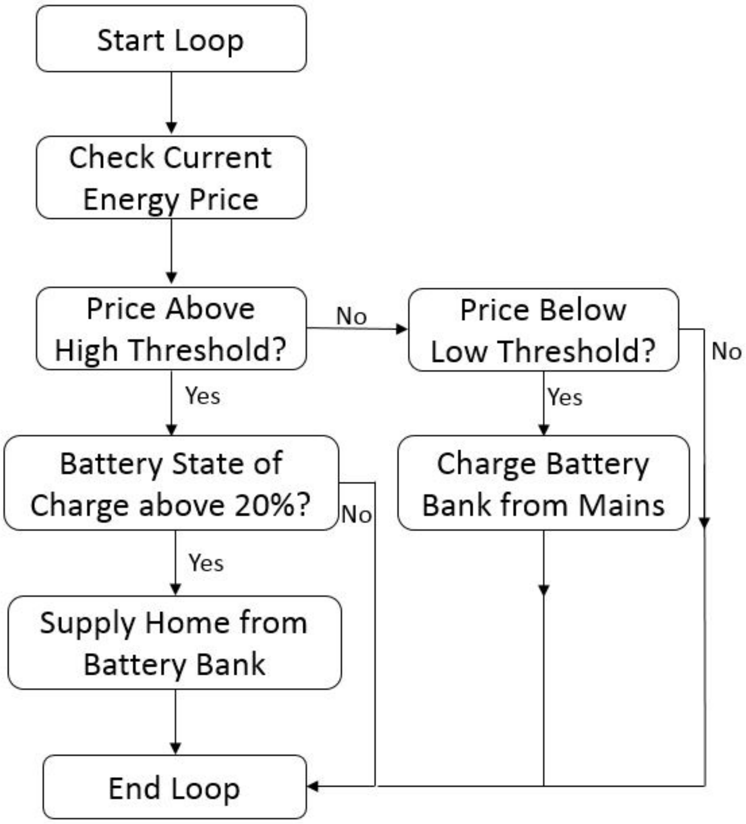


FIGURE 5.4: Simple Load Shifting Algorithm

Figure 4.28 in Chapter 4 shows the general mounting technique for the PV panels. The gap between the PV and roof panels along with sealed flashings around the perimeter of the PV panels creates the necessary enclosed air channel for the thermal energy system. To complete the active system, motorized air control flap valves and fans are used to direct the air flow in to or out of the building flaps to maintain a comfortable internal temperature and to maximize energy efficiency. The majority of the BIPV/T and Ventilation equipment will be enclosed in the void above the bathroom ceiling. This space provides an isolated environment for the equipment that can be sound-insulated to ensure the systems do not interfere with the occupant's standard of living.

5.3.1 Air Control Valves

Four sets of air control valves will be used to coordinate the building's thermal recovery modes. Two of the valve sets allows the underside of the PV panels to vent to ambient air in times of elevated solar resources and ambient temperatures. The other two valve sets control the air flow between the thermal system and the interior of the building. Figure 5.5 shows a profile view of the building with the valve sets highlighted.

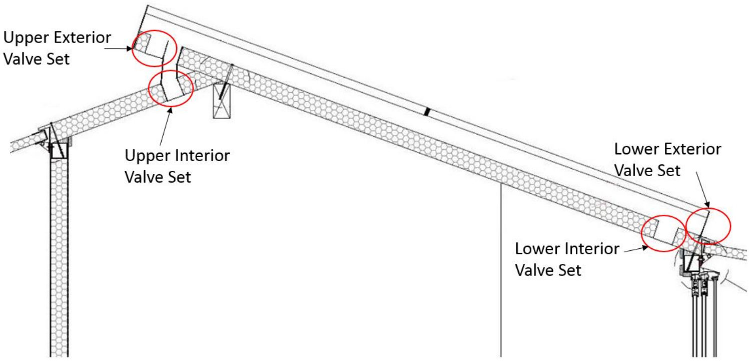


FIGURE 5.5: Illustration of Air Control Valves

The type of valve that will be used will be servo operated flap valves because of its simple construction and therefore reliability. This type of valve has been successfully implemented in Dennis Chapman's Eco-Castle for air circulation. The flap can be made of a variety of readily available building materials and so the valve can be design to be aesthetically neutral in the building.

The lower interior circulation valves are mounted in the roof panels and so will effectively be piercing the buildings secondary weather tight envelope. Consideration of this effect is required to ensure that this secondary envelope remains weather tight. A plastic cowl will be fitted over the opening above each valve allowing only the movement of air through the opening. Figure 5.6 shows the section view of the flap valve and plastic cowl.

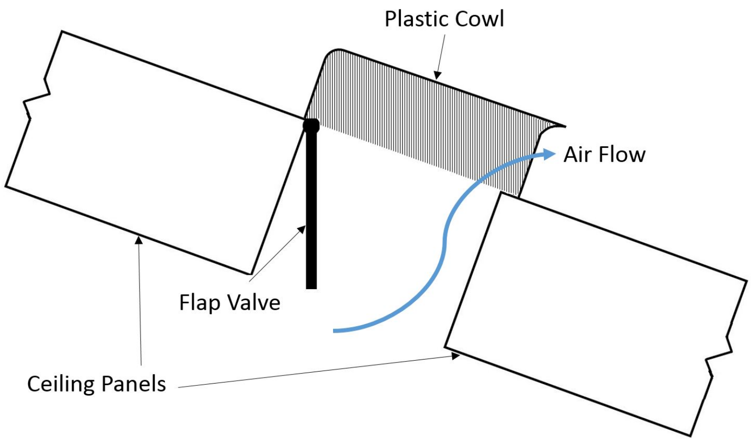


FIGURE 5.6: Profile of Air Control Valve and Plastic Cowl

5.3.2 Fans and Ducting

Forced convection by means of electric fans will be used to increase the efficiency of the PV Thermal system. It has been validated in Chapter 6 that the efficiency of a BIPV/T system will peak at a particular air flow rate and so fan selection and mounting will have a significant effect on the system's overall efficiency. The required air flow rate for the installed system can be calculated with the data collected from the single panel Test Rig. The required air flow rate will be further detailed in Chapter 6.

An inline centrifugal type fan will be used in the design to produce the necessary air flows. A series of flexible ducts will be used to draw the heated air from the top of the PV Panels near the roof ridge, through the centrifugal fan and then into the interior of the building. Figure 5.7 shows an example of the type of fan that will be used in the design.

Figure 5.7: Inline Centrifugal Circulation Fan

To achieve equal airflow underneath all of the PV panels using a single fan, the ducting will be arranged to form a type of manifold at the top of the PV thermal system. This equal distribution of airflow is essential in maximizing the efficiency of the thermal system.

5.3.3 Ventilation System

The building envelope is designed to be as air tight as possible to minimize heat losses due to infiltration. This feature increases the thermal efficiency of the building, but it can result in insufficient natural ventilation. A counter-crossflow heat exchanger will be utilized to provide heat-efficient ventilation for the building. Figure 5.8 shows a diagram of a counter-crossflow heat exchanger in operation.

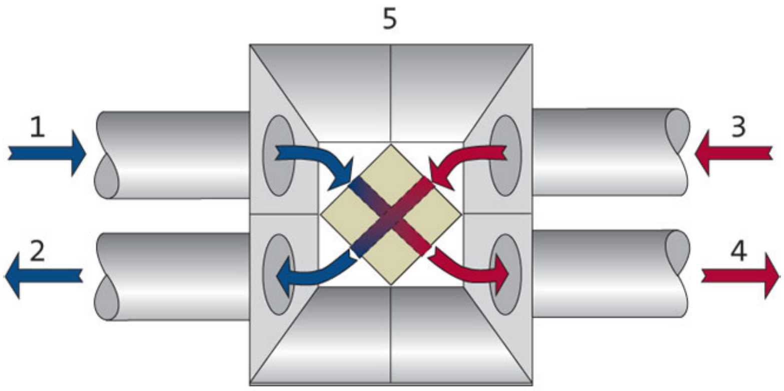


FIGURE 5.8: Counter Cross Flow Heat Exchanger. 1-Cool Fresh Air. 2-Cool Stale Air. 3-Warm Stale Air. 4-Warm Fresh Air [12]

Two centrifugal fans will be used to actively control flow through the counter-crossflow heat exchanger. The ventilation rate will be determined by CO_2 concentration readings taken from sensors placed within the building with the concentration being maintained at a comfortable level recommended by the World Health Organisation. The ventilation system will run at the lowest speed possible to maintain this concentration to minimize energy input.

Ventilation Systems will be situated in the void above the bathroom ceiling with ducting entering and exiting the building on the rear wall. The ducts will have flap air control valves where they pierce the rear wall in order to minimize heat transfer while the ventilation system is inoperative. Figure 5.9 shows a section view of the ventilation system layout.

5.3.4 Control Electronics

All control within the building will be undertaken with the use of ballast electronics that have been designed and manufactured by DARC Technologies Ltd. The ballast units are

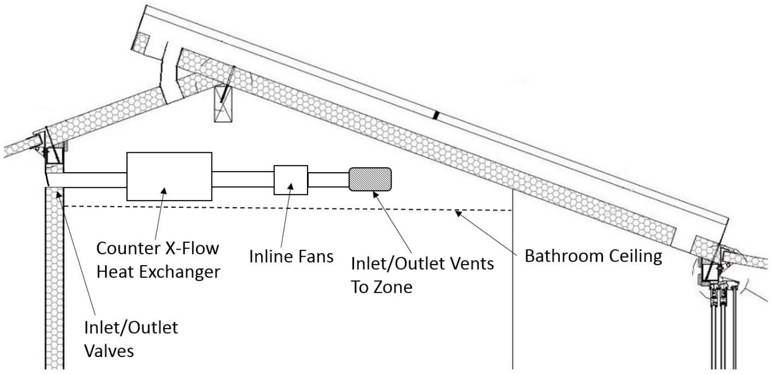


FIGURE 5.9: Illustration of Ventilation Sytem Layout

powered from a 48V bus that runs throughout the building and the communications are realized via a Signal-Over-Powerline carrier system that utilize the same bus. The units are capable of eight analog/digital inputs as well as four 48V PWM capable outputs. The Ballast Units and Signal-Over-Powerline system will be further detailed in Section 5.3.

A central control system is required to coordinate the Ballast units into a cohesive network. This central unit can be any digital device capable of managing and storing multiple command algorithms and serial communications. The system that will be utilized in this design is the Beaglebone micro-computer running a modified version of Linux. The Beaglebone was utilized in Dennis Chapman's Eco-Castle because of its low cost and low level input capability. The Beaglebone will act as a command server that is directed by the building's occupant with the use of everyday devices such as smart phones.

5.3.5 Control Modes

There will be multiple thermal control modes available with the use of the air control valves and centrifugal fan. These modes will be automatically selected by the command server according to the desired interior temperature of the building. The control modes and their functions are itemised as follows:

Internal Circulation The primary control mode will be internal circulation wherein the interior air of the building is continuously circulated underneath the PV Panels to effect an increase in zone temperature. This mode is one of the main sources of heat energy for the building and will operate as frequently as possible to harvest the maximum amount of energy from the PV Panels. The centrifugal fan will run at the lowest possible speed that still provides a low temperature rise over the PV Panels to increase their efficiency. Figure 5.10 illustrates the internal circulation control mode.

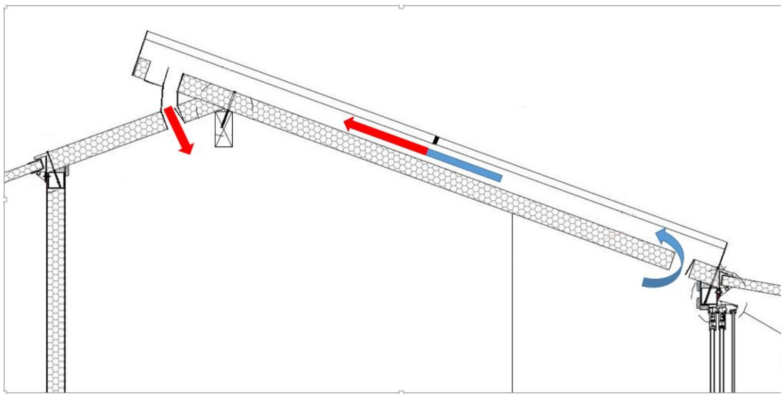


FIGURE 5.10: Air circulated internally for maximum thermal gain

Heat Controlled Ventilation If the interior of the building approaches an over temperature condition, the inlet air to the underside of the PV panels can be taken from the cooler exterior air. Fan speed can be controlled to ensure the air being drawn in to the building is at the desired interior temperature. This mode allows accurate control of the interior air temperature of the building while eliminating the use of the Primary Ventilation system and still providing forced cooling of the PV Panels. This mode can also be used to cool the interior of the building at night during extended periods of high outside temperatures during the day. Figure 5.11 illustrates the Heat Controlled Ventilation control mode.

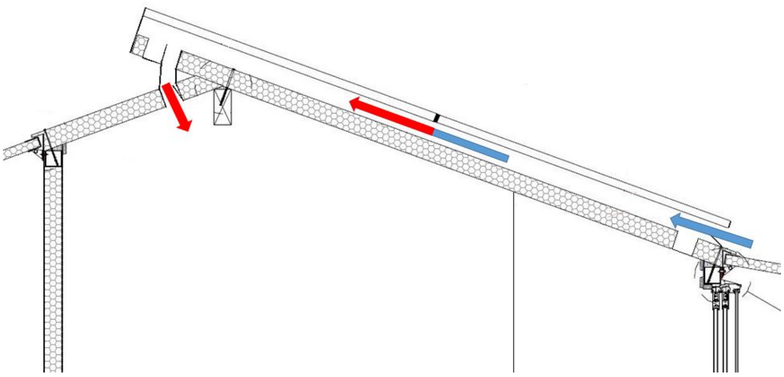


FIGURE 5.11: Air is drawn under the panels from outside with a modulated flow to control internal temperature

PV Panel Venting In the case of the outside air temperature being greater than the interior air temperature of the building, both of the interior sets of valves will be closed while both exterior sets of valves will be opened. This configuration will allow natural convection cooling of the PV Panels to ensure that they are operating as efficiently as possible and will attempt to isolate the interior air zone, minimizing the increase in temperature. Figure 5.12 illustrates the PV Panel Venting control mode.

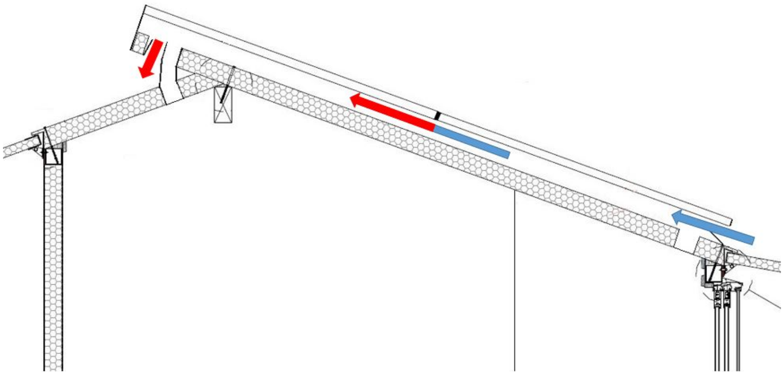


FIGURE 5.12: PV panels are vented at the top and bottom of the roof to allow natural convection cooling

Maximum Insulation This criteria will be the typical night time control mode, with all valves in the closed position. The air pocket created between the roof and PV panels provide additional thermal insulation for when there are negligible solar resources and the outside temperature is below the interior temperature of the building. Figure 5.13 illustrates the Maximum Insulation control mode.

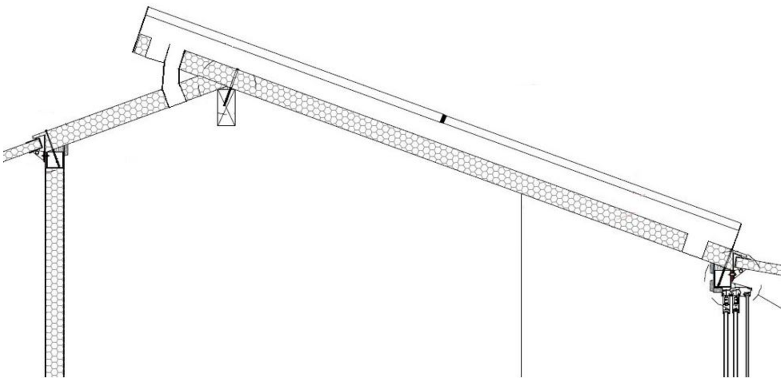


FIGURE 5.13: All air control valves are closed to utilise the PV panel duct as an insulating air gap

5.4 Electrical Services

5.4.1 Power Supply Bus's

The 48V battery pack in the off-grid power system will be the primary source of electrical energy in the building. Using energy directly from the battery pack reduces the load on the power inverter, increasing efficiency and reducing the capacity requirement of the inverter. A 48V DC power bus will run throughout the building on to which ballast units and switches can be connected to become part of the network.

The power inverter specified in this design, the Outback 3000, quotes a maximum efficiency of 95%. Any power that is consumed through the 48V DC Bus will avoid a minimum of 5% energy loss when load would have otherwise been placed on the power inverter.

While the use of the 48V DC bus is preferred due to efficiency gains, it is acknowledged the majority of everyday appliances are designed to utilize 240V AC power and typical occupants will be accustomed to using these appliances. For this reason, standard NZ/AU 240V outlets are provided in the building, supplied by the power inverter.

5.4.2 Signal Over Power-line

The NZ industry standard for home electrical wiring takes the traditional approach of series wired mechanical switches to provide a complete electrical circuit for devices such as lights, fans and mechanical actuators. This system has the benefit of simplicity, but it can be very labour and materials intensive to install, as each switch must be individually wired to its respective device.

DARC technologies have designed a power-line-carrier system that only requires a home to be wired with a power bus of any voltage; AC or DC. All switches and devices are connected as nodes on the system with any switch capable of controlling any device throughout the building. Each device on the network is given a unique software address and can be set to operate from either a preprogrammed switch within the building, or from a personal smart device that is connected to the Signal Over Power-line network.

A high carrier frequency is filtered out of the power bus within the ballast units to provide the cleanest possible voltage to powered devices. Filtering the signal in the ballast is good practice, but due to the high frequency and low amplitude of the signal, it would provide little to no disturbance to a device that was directly connected to the main power bus without the use of the ballast unit.

Ballast units are the interface between the signal network and the device to be controlled. The units are capable of not only applying power to a device, but can apply variable DC voltage through the use of PWM. This variable voltage can be applied to lights to create a dimming effect and to motors to effect variable speed. The standard size ballast unit is capable of four separate outputs as well as six general purpose input/outputs for receiving signals from any kind of electrical sensor. For example, a CO_2 concentration sensor will be used in the Ventilation system.

The switch units come in many different shapes and sizes to suit most typical residential applications. Common household single, double and quadruple rocker switch units are replaced with button switches of their respective size. The button switches do not have a mechanical indication of the controlled devices state but instead have soft LED's above the buttons for indication.

This complete system is currently used in Dennis Chapman's Eco Castle where it has surpassed the prototype stage, ready for production.

5.4.3 LED Lighting

DARC Technologies Ltd have designed a LED lighting system around their Ballast units to take advantage of the variable, 0-48V supply. Lighting options are centered on providing an efficient ample light source within a building while eliminating lighting styles that compromise the buildings thermal performance such as recessed, in-roof lighting fixtures. The main lighting model that will be used in this design are the wall mounted up-lights. Figure 5.14 shows a wall mounted up-light.

The Up-lights are produced in 1.5m lengths, each containing 20 LEDs for a maximum power consumption of 30W. A clip is provided for connecting multiple lengths together into one continuous lighting array. Ballast units are built in to the lights making for a simple two wire installation.

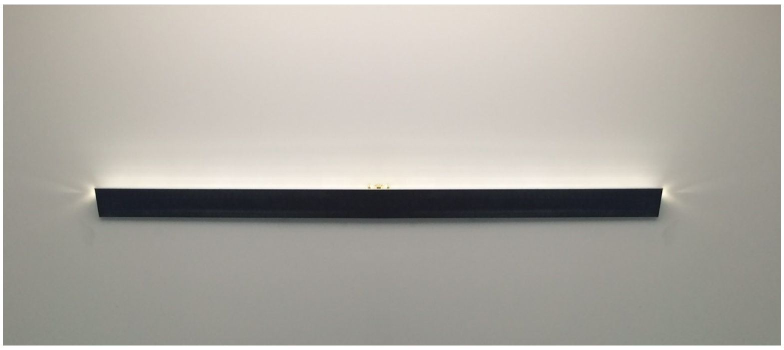


FIGURE 5.14: Wall Mounted LED Up-Light

5.4.4 Electrical Diagram

Figure 5.15 shows a block diagram of the buildings electrical systems.

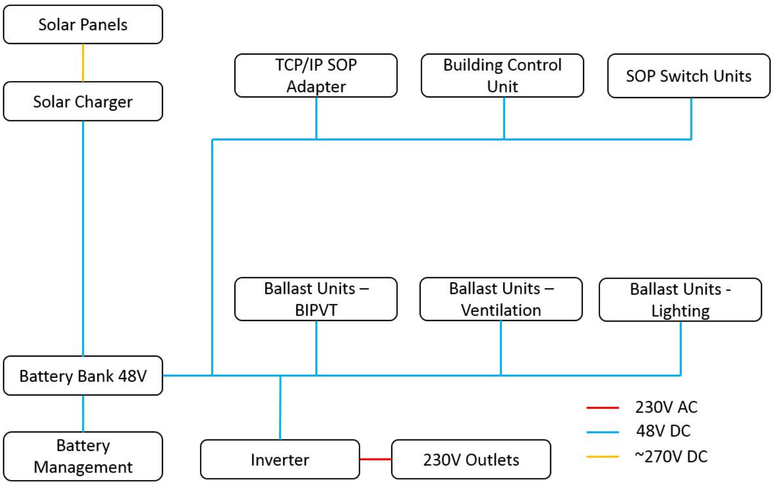


FIGURE 5.15: Block Diagram of Components in the Electrical Power System

Chapter 6

Results & Analysis

6.1 Test Rig Results

6.1.1 Mass Air Flow Analysis

Airflow in the test rig of Figure 3.5 was controlled by a variable speed axial flow fans. Testing with the anemometer showed that the average air speed within the duct could be set from 0ms^{-1} to 1.9ms^{-1}. To extract the maximum thermal power from the back of the PV panel, the airspeed should be as high as practicable to gain a high differential temperature between the circulating air and the panel. As the air speed increases, returns by way of energy transfer will be diminishing, reaching a point where the input power in the circulating fans becomes comparable to the increase in harvested heat energy. It was hypothesized that with a fixed incident solar irradiation, there will be a fan speed that give maximum system efficiency.

$$\eta_{therm} = \frac{P_{Therm} - P_{Elec}}{A_{PV} G_T} \tag{6.1}$$

Measurements were taken on a clear day over one hour centred on the solar day to have similar solar irradiation at all data points. Furthermore, solar irradiation would be accurately measured and used to normalize the data during analysis. Six air speeds were measured at intervals of 10min along with the corresponding total fan electrical power and thermal output power. At each fan speed, input electrical power was subtracted from the output heat power and normalized with the solar irradiance power to calculate the system efficiency, shown in Equation (6.1). Figure 6.1 shows a graph of the efficiency from Equation (6.1) vs air speed.

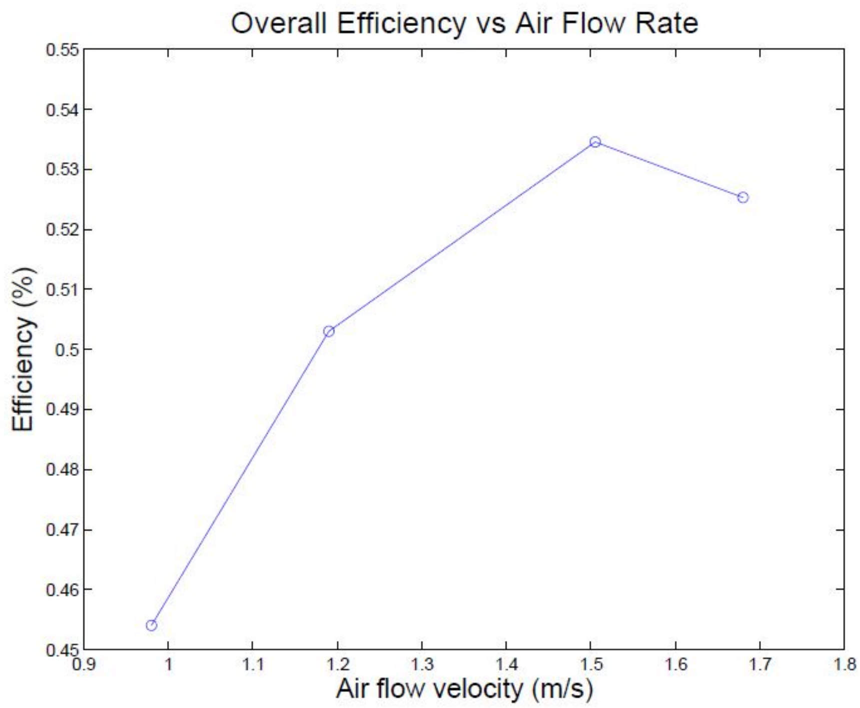


FIGURE 6.1: Graph of Overall Efficiency Over a Range of Air Flow Rates

For the thermal system in the test rig, at a solar radiance of 950-1100Wm^{-2} the most efficient air speed is shown to be 1.5ms^{-1} which corresponds to a mass airflow of 1kgs^{-1}. This value is highly dependent on the overall system and although the layout of the test rig is similar to that used in the building design in this project, the airflow characteristics are expected to be different.

6.1.2 Maximum Thermal Output

The test rig was run at maximum air speed over a time period of 2 hours on multiple days to gain a broad data set that could be analysed to determine the total heat power output. For all tests the tilt of the solar panel was set to 30 degrees as this value was the roof pitch of the design in this project at the time of testing. Figure 6.2 shows a graph of the output heat power over a single day of testing with the ambient temperature overlaid.

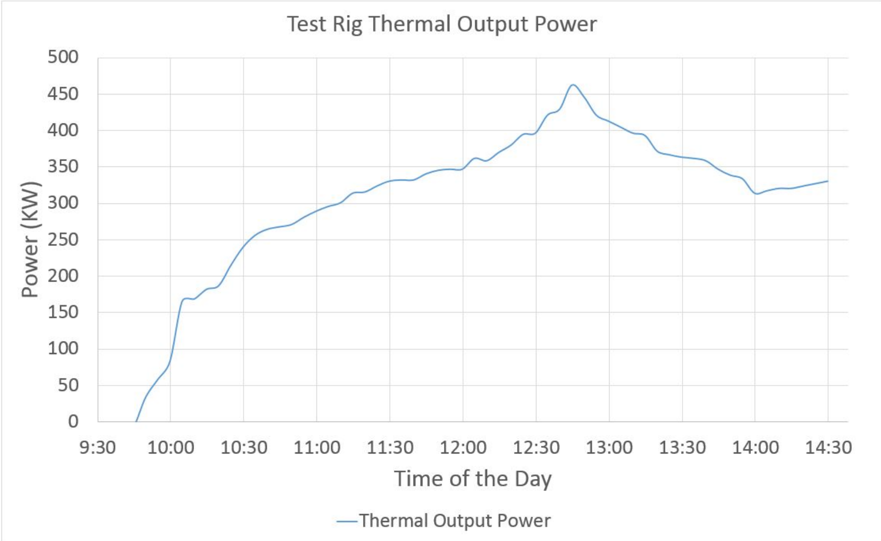


FIGURE 6.2: Test Rig Thermal Output Power over a single test period

The above graph was created using data taken on the May 25th 2015 which is near the middle of autumn. At this time of the year the maximum solar angle is 35 degrees, providing a midpoint between summer and winter angles. The total heat energy collected from the solar panel throughout the test was calculated to be 4kWh.

It can be seen in Figure 6.2 that the maximum output of the panel throughout the day does not directly coincide with the maximum solar irradiance which is at 12pm. The rising ambient temperature reduces the amount of heat energy lost to the atmosphere and so increases the heat energy output of the thermal harvesting system. Thus, the ambient temperature has a direct effect on the efficiency of the system.

6.1.3 Thermal Efficiency

Figure 6.3 shows the thermal efficiency of the PV panel over a single test period. It can be seen that the thermal efficiency of the Test Rig increases significantly as the ambient temperature increases.

The thermal efficiency equations given in Equations (3.1)-(3.3) in Section 3.2.3 characterize the thermal energy system. These equations are used to normalize the data taken from the test rig to calculate its characteristic efficiency curves. Data was taken from several days of testing but was only data points taken while the thermal system was at steady state were used in calculating efficiency. Figure 6.4 shows the characteristic efficiency curve of the test rig.

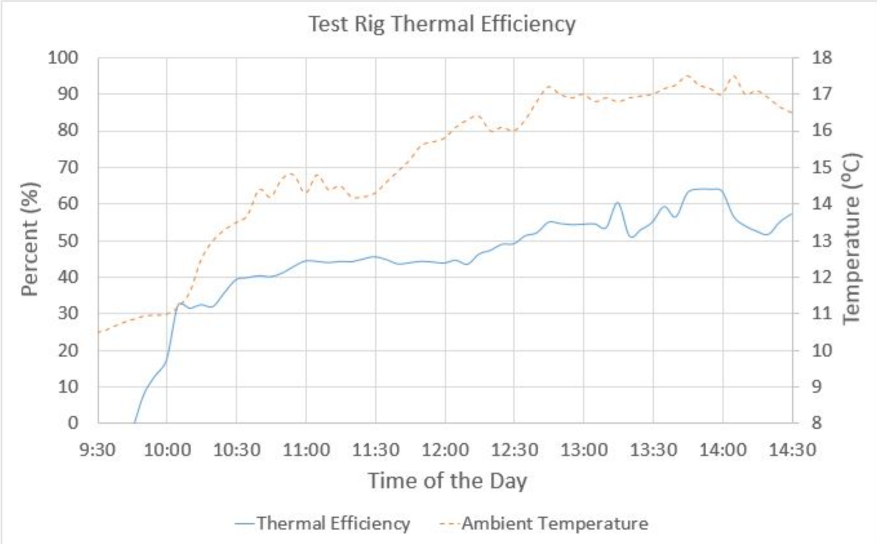


Figure 6.3: Test Rig Thermal Efficiency over a single test period

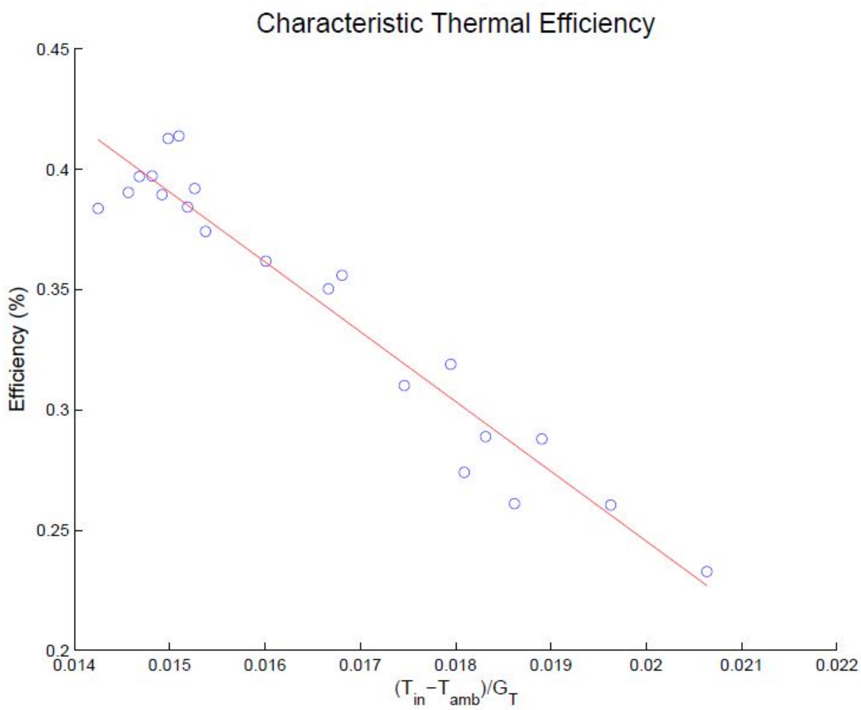


Figure 6.4: Characteristic Efficiency Curve of the Thermal Collector

Duffie et al. states that the characteristic efficiency curve of any solar thermal collector should have a negative slope as this property shows that efficiency is inversely proportional to the ambient air temperature [13]. The curve in Figure 6.4 does have a negative slope but is not directly linear. The linear line of best fit has an R^2 value of 0.85. Non-linearity's in the curve could have been from deficiencies in the thermal insulation in the rig, causing inaccurate temperature readings.

Over the entire data set, the average efficiency was calculated to be 43%, and the implications of the effect that this efficiency has on the viability of this system will be detailed in Section 6.2.

6.1.4 Maximum Electrical Output

At all times during the collection of thermal data on the test rig, the solar panel was loaded so that the electrical characteristics of the PV Panel could be analysed while installed in the BIPV/T system. Section 3.1 describes the hardware and the MPPT algorithm used to harvest the maximum amount of electrical power from the PV panel. As stated previously, all data was collected with the panel angle at 30 degrees. Figure 6.5 shows the electrical power output of the PV panel over a single test period. The total energy collected during the test period was 0.5kWh.

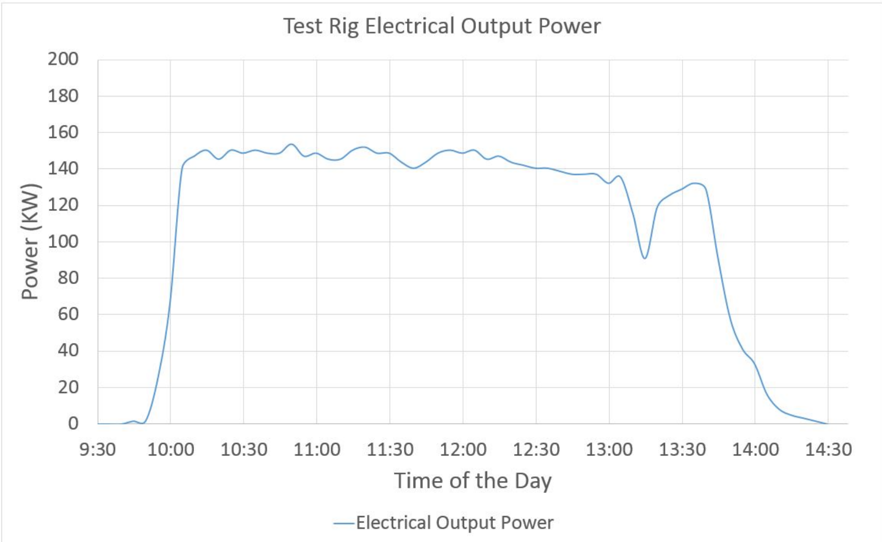


FIGURE 6.5: Test Rig Electrical Output Power over a single test period

6.1.5 Electrical Efficiency

The electrical efficiency equation is outlined in Section 3.2.2. Figure 6.6 shows the electrical efficiency of the PV panel over a single test period.

The maximum efficiency of 24.5% is realized in the earlier hours of the test period while the ambient temperature and thermal output power are at their lowest. This result indicates that there is a significant increase in PV cell temperature as the test progresses, lowering the panels efficiency appreciably.

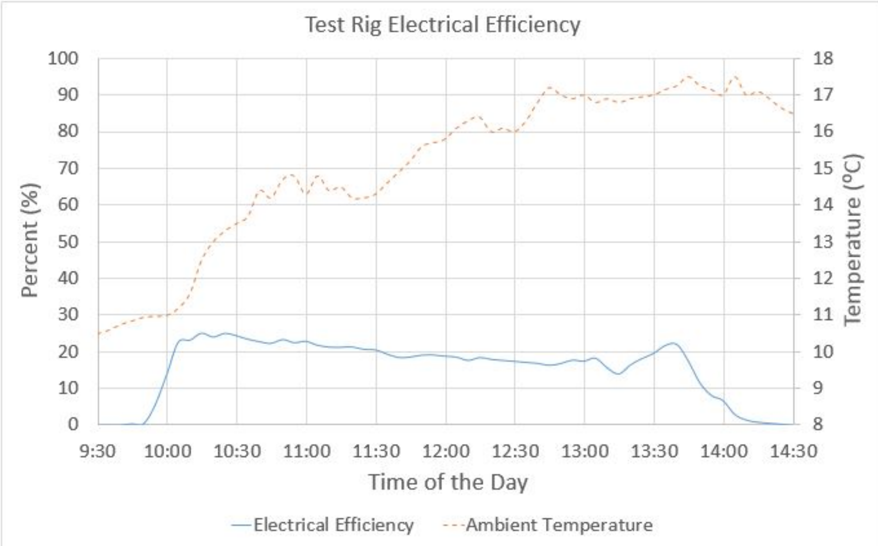


Figure 6.6: Test Rig Electrical Efficiency over a single test period

6.1.6 Cell Temperature Dependency

As stated in the previous sub-section, the cell temperature had a significant effect on the efficiency of the PV panel. A secondary test rig was constructed to provide free ventilation to the rear of a PV panel to quantify the loss of efficiency due to the enclosed nature of the PV panels in the design of this project. The test rig was left to run for a period of one month to gain a comprehensive data set. For comparison to the thermal test rig, data was selected that closely matched the data used in Figure 6.6. Figure 6.7 shows the efficiency of the secondary test rig over a single test period.

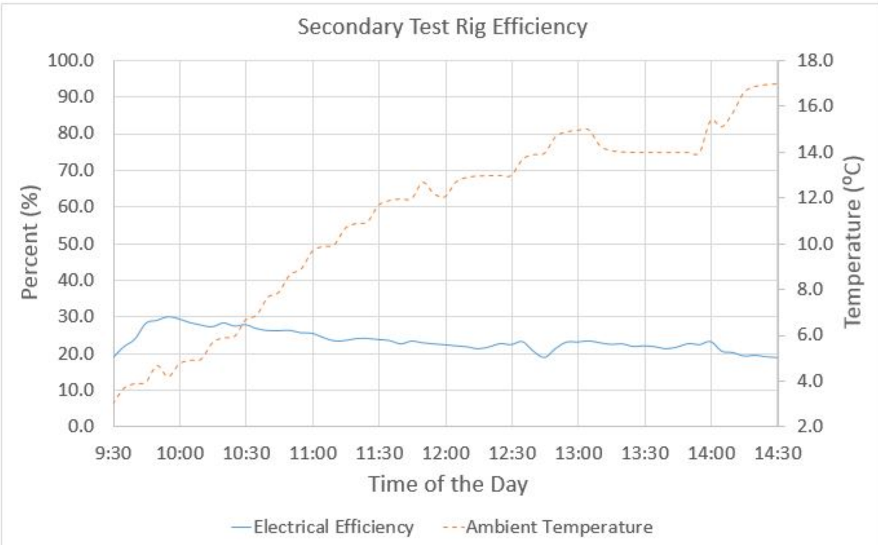


Figure 6.7: Secondary Test Rig Electrical Efficiency over a single test period

The maximum efficiency in Figure 6.7 is 29.9%, 5.4% higher that the peak efficiency of the PV panel installed in the thermal test rig. The peak efficiency was realized with an ambient temperature of 4.2°C in the unshrouded panel compared with an average behind panel temperature of 30°C in the thermal rig at the point of peak efficiency.

Appendix A shows the datasheet of the PV panel used in both the test rigs. Efficiency is rated at 20% at a cell temperature of 20°C with a solar irradiation of 1000Wm^{-2} and has a temperature dependence efficiency value of 0.5%°C^{-1}. The cell temperature is not measured in either of the test rigs, but the behind panel air temperatures can provide a rough indication of the difference in cell temperature between the PV panels of each test rig. The efficiency difference of 5% between the test rigs indicates a cell temperature differential of 10°C, although the difference in behind-panel air temperatures is 16°C. The thermal test rig provides consistent, forced cooling of the PV panel while the solar test Rig relies on natural convection and wind to cool the panel.

The lower electrical efficiency of the thermal test rig affects the viability of the BIPV/T which will be detailed in Section 6.2.

6.1.7 Conclusion

The Thermal Test Rig has given valuable data on the actual thermal and electrical energy outputs of the PV panel model that will be used in the design of the transportable building in this project. The average electrical from the larger data set was 15% and the average thermal energy efficiency was 20%. When compared with the Solar Test Rig, the electrical efficiency in the Thermal Rig is down 5% from 20% but the added thermal energy recovery increases the overall recovery efficiency of the PV panel to 35%. The Test Rig has shown that there is an optimum fan size and air flow speed in the thermal duct for maximum thermal output efficiency, with the efficiencies dropping to 50% of the peak efficiency under low flow conditions and to 95% under excessively high flow conditions.

6.2 Building Energy Analysis

6.2.1 TRNSYS

TRNSYS is a PC based energy modelling suite with comprehensive capabilities. It is primarily used in the modelling of thermal zones in residential and commercial building. Physical characteristics of a building can be imported into the software and subjected to long-term simulations using real historical data. The basic dimensions of the building design were modelled in Google Sketchup to be imported into TRNSYS. Figure 6.8 shows the imported Sketchup model.

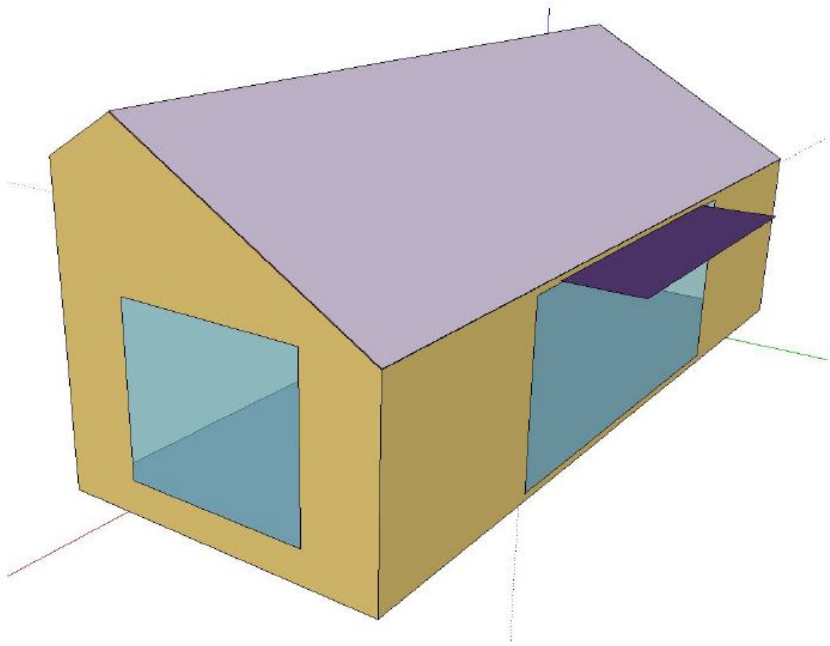


FIGURE 6.8: Sketchup Model Imported in to TRNSYS for Energy Modelling

The model is a simplification that indicates to the TRNSYS engine quantities such as surface areas, air volumes, glazing area and thermal insulation. Forecasted external conditions are synthesised from historical data from the NIWA meteorological organisation. Using modelled building and external conditions, TRNSYS performs iterative calculations over the desired time period.

TRNSYS outputs energy flow quantities and zone temperatures which are then passed through a post-processing script in Matlab. The post-processor performs adjustments and additions to the raw data to make it easily displayed for analysis.

6.2.2 Building Insulation

Table 4.1 in Section 4.4.6 shows the R values of all the materials used in the building design with the resulting overall R value of the building being 1.82. This number does not seem to be appreciably high when compared to current typical insulation materials as it includes all thermal bridging within the building structure. Figure 6.9 shows the average daily energy loss through heat conduction over the period of one year.

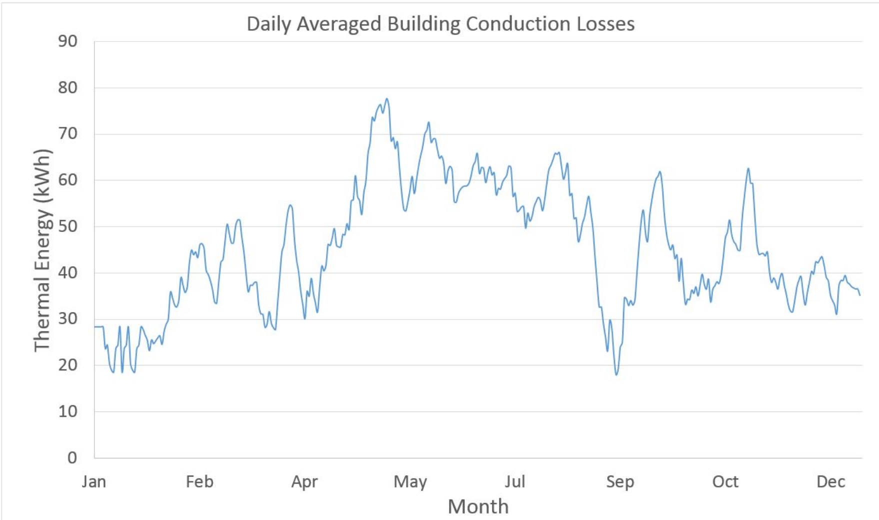


Figure 6.9: Daily Averaged Building Thermal Loss due to Conduction

Heat conduction is proportional to the temperature differential across the building insulation and the forces cooling effect of the wind. Therefore, the day on which the energy loss reaches a peak will coincide with the day that maximises the sum of the lowest average ambient temperature temperature and highest average wind speed. The peak energy loss in a single day is 78.3kWh.

6.2.3 Thermal Mass

Throughout the design process, the amount of internal thermal mass in the building changed significantly owing to cost and ease of construction benefits. The function of internal thermal mass is to dampen transient temperatures within a building. This effect allows the interior of the building to absorb energy from solar resources during the day that would otherwise be wasted by excessive ventilation due to over temperature conditions.

The differing quantities of thermal mass were modelled to determine the effect on the overall thermal performance. Simulations were run with the only energy input being solar irradiation through the glazing in the building and energy losses being conduction through the building envelope and a small amount of infiltration. Figure 6.10 shows the daily averaged internal air temperature of the building over a period of one year with different quantities of thermal mass.

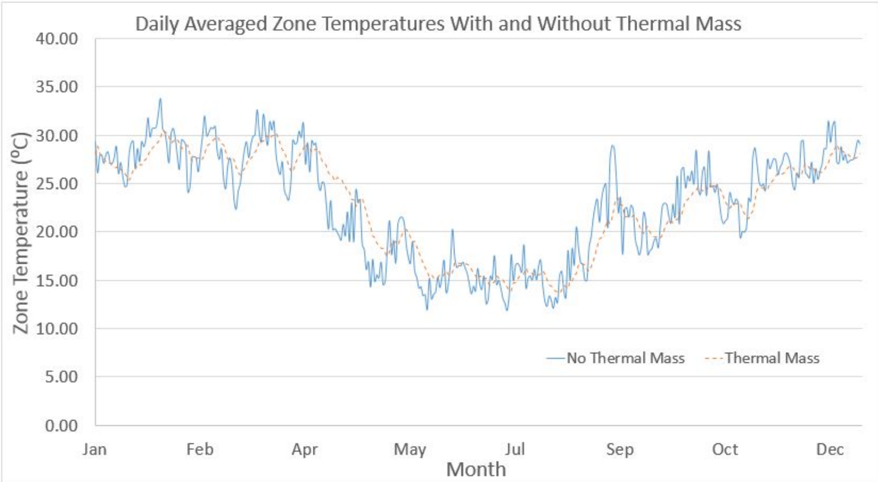


Figure 6.10: Daily Averaged Zone Temperatures With and Without Thermal Mass

The graph shows a significantly more narrow temperature range for the curve representing the building design with good thermal mass, with a winter low of 13.9°C and a summer high of 30.5°C. In the case of no appreciable thermal mass, the internal air temperature is significantly following the outside air temperature.

6.2.4 Infiltration

Infiltration can account for a significant proportion of heat energy losses in a residential in some cases account for up to 20% of a buildings total losses. The Passive Haus standard in Europe calls for an extremely low infiltration rating with one of the final building tests being a pressurized leak test. Different infiltration rates were simulated to determine the effect of infiltration on the overall thermal performance of the building design. Two infiltration rates were simulated with the higher attempting to emulate a typical aged building with a high infiltration rate and the lower value attempting to emulate a modern building with low infiltration. Simulations were run with only solar irradiation as the energy input through the glazing in the building. The energy losses were conduction through the building envelope with a fixed internal thermal mass. Figure 6.11 shows the average daily internal air temperature over the period of one year with differing infiltration rates.

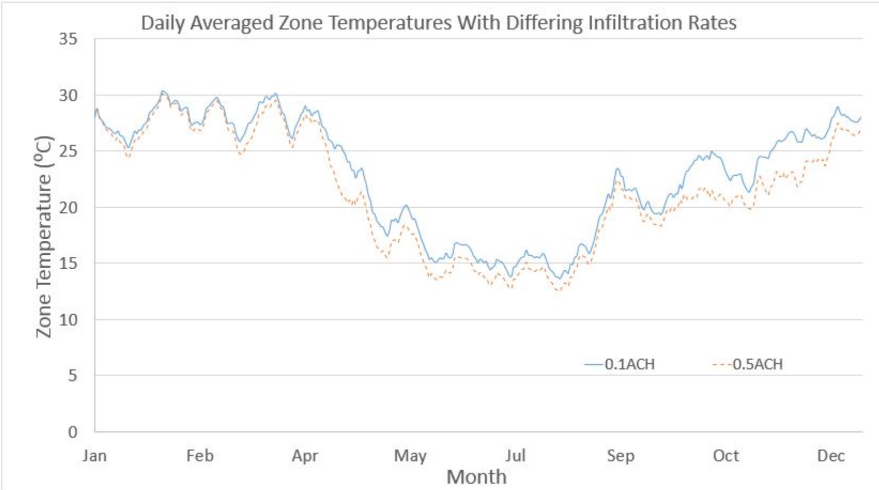


Figure 6.11: Daily Averaged Zone Temperatures With Differing Infiltration Rates

The maximum infiltration rate of 0.5ACH shows a minimum internal temperature of 12.7°C, 1.7°C lower than the lower infiltration rate of 0.1ACH. Even a small increase in infiltration results in a significant heat loss in this building design. The infiltration for the building design will be kept as low as possible with the only non-sealed components being the sliding doors. The estimated infiltration rate of the building is less than 0.05ACH.

6.2.5 BIPV/T Thermal Gain

The BIPV/T system will be the primary source of energy for the building, with an active thermal control system set to maintain a comfortable internal temperature. Figure 6.12 shows the potential daily harvested energy over one year.

A major limitation of the BIPV/T system is the requirement to keep the internal temperature under a set value, forcing the system to halt energy harvesting if the internal temperature gets too high. This approach limits potential energy recovery on days with high solar resources. Simulations were performed using different maximum temperature values to determine the losses incurred by capping the maximum temperature of the building. Figure 6.13 shows the daily kWh produced over the period of one year with differing maximum temperatures.

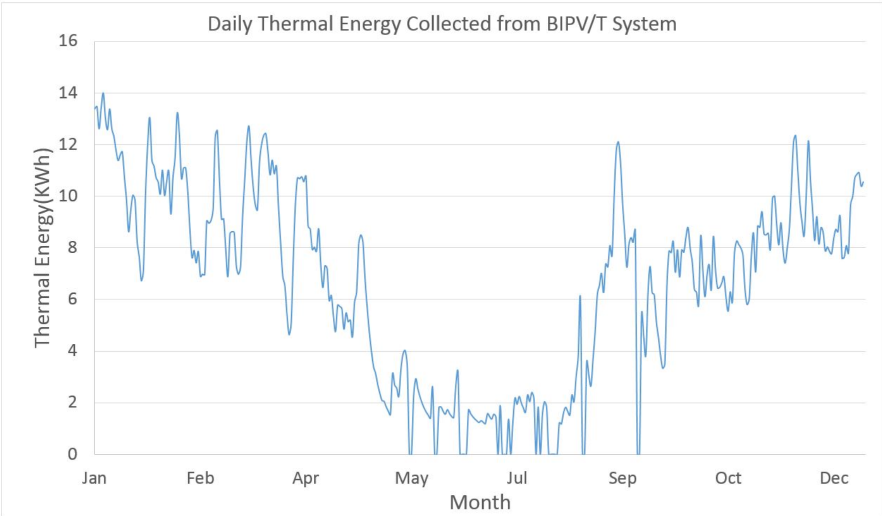


Figure 6.12: Daily Thermal Energy Collected from BIPV/T System

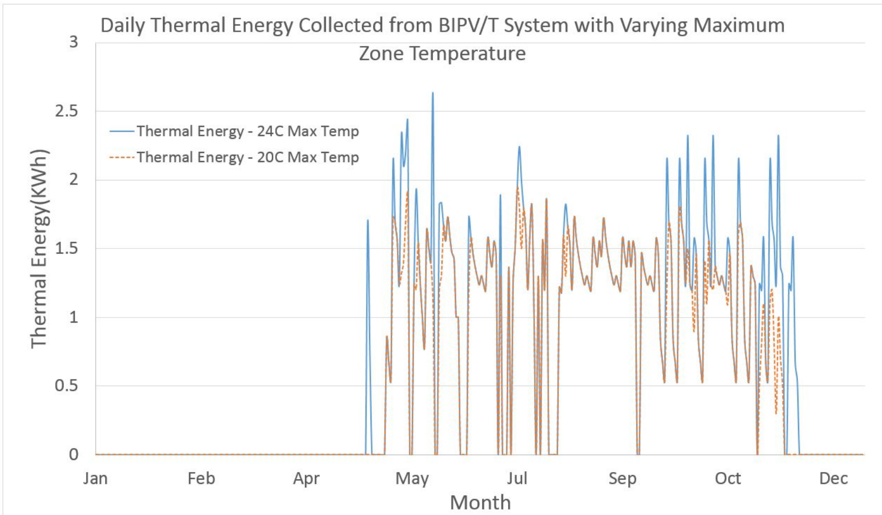


Figure 6.13: Daily Thermal Energy Collected from BIPV/T System with a Maximum Zone Temperature of 24°C

With the maximum internal temperature maintained at 20°C the total energy unable to be harvested yearly is 212kWh. This value is significantly higher than with the maximum temperature of 24°C, equating to 243kWh of unharvested energy. The difference is especially noticeable in the winter season. For this reason the thermal control algorithm allows for a maximum temperature of 24°C with a provision for occupants to input exceptions for when they are in the building during the day.

6.2.6 Natural Solar Gain

Natural solar gain accounts for the majority of the input thermal energy to the building. The flooring of the design has been specified as polished concrete to maximise the absorbed incident solar energy. Figure 6.14 shows the daily absorbed solar incident energy over the period of one year.

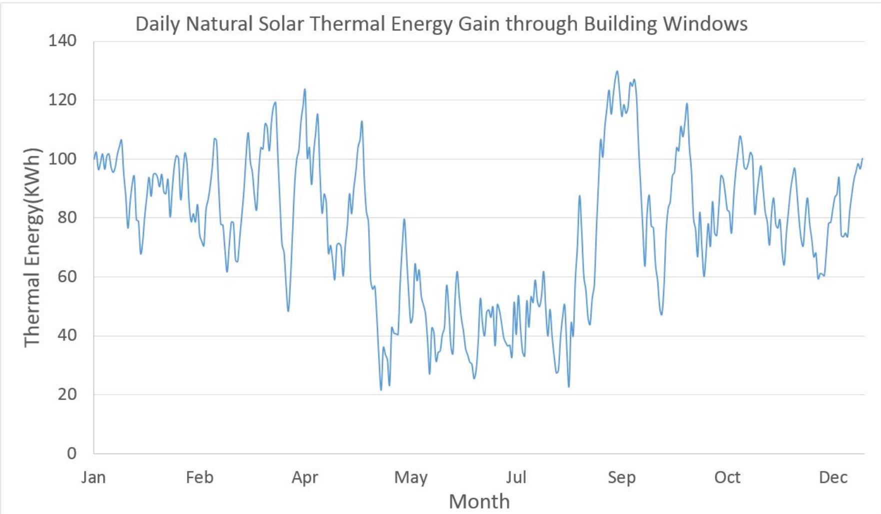


FIGURE 6.14: Daily Natural Solar Thermal Energy Gain through Building Windows

The absorbed energy stays relatively constant throughout the different seasons due to the angle of the front awning in the building design.

6.2.7 Ventilation Losses

Ventilation in the building is performed by an arrangement of fans and a counter cross-flow heat exchanger. The system is estimated to be up to 90% efficient but the ventilation rate can still contribute significantly to heat losses in the building. The ventilation control system is designed to continuously measure the CO_2 concentration in the building and to control the fans to achieve a predetermined set point.

The energy loss associated with the ventilation rate depends on the inside and ambient temperatures. Figure 6.15 shows the estimated daily energy loss due to ventilation over the period of one year. The largest energy loss of 1.0kWh occurs during winter with the largest differential between the inside and ambient temperatures.

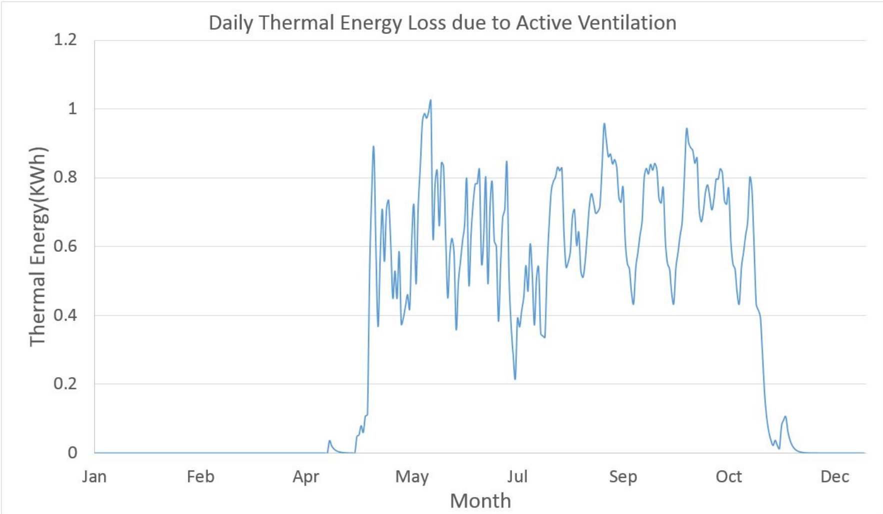


FIGURE 6.15: Daily Thermal Energy Loss due to Active Ventilation

6.2.8 Thermal Energy Deficit

The primary directive in the thermal control system is to maintain the internal temperature of the building between 16°C and 24°C with an ideal target of 20°C. As the primary heat source only delivers energy during sunlight hours there is the potential for a thermal energy deficit at night and during times of low solar resources. Figure 6.16 shows the simulated internal temperature of the building with no auxiliary heater input.

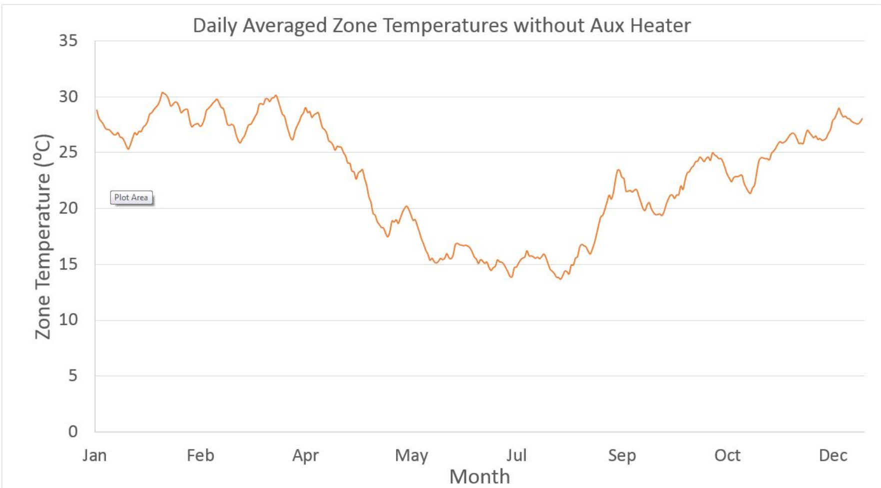


FIGURE 6.16: Daily Averaged Zone Temperatures without Aux Heater

The temperature falls to 13.9°C which is outside of the acceptable range. The use of a resistive electric heater is simulated as a secondary heat source to maintain the temperature at a minimum of 16°C. Figure 6.17 shows the same simulation as Figure 6.16 but with the secondary heat source added and also shows the daily electrical energy required to run the heater. On the worst night during the simulated month the total electrical energy consumed is 6.3kWh. This will impact the design of the off grid storage system, increasing its required capacity.

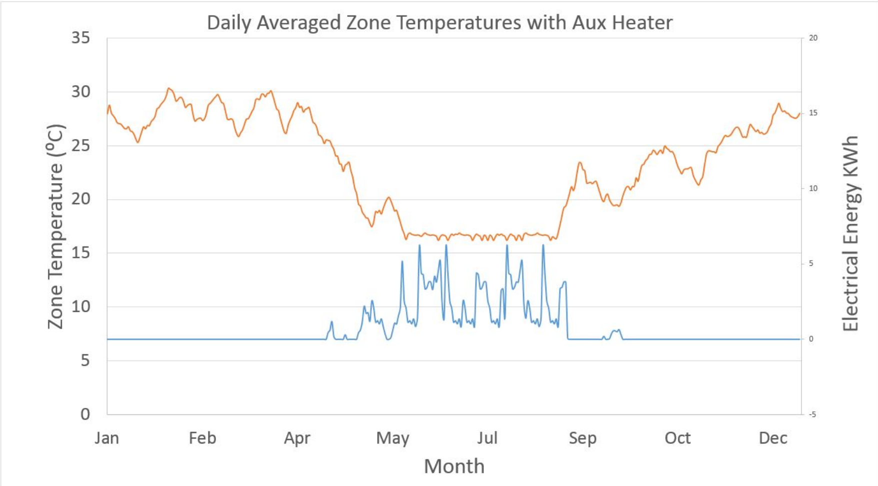


FIGURE 6.17: Daily Averaged Zone Temperatures with Aux Heater

6.2.9 Electrical Energy Production

Electrical energy production for the building integrated PV system can be estimated using the TRNSYS model. Figure 6.18 shows the daily electrical energy production over the period of one year.

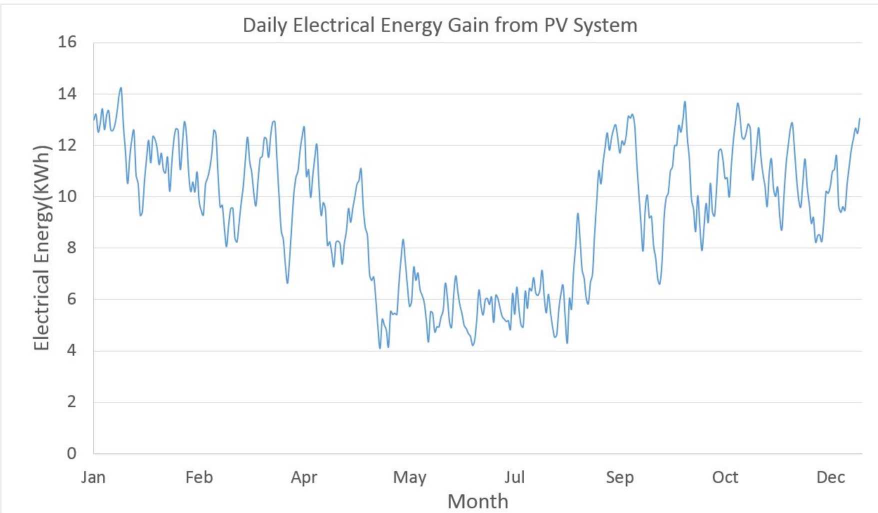


FIGURE 6.18: Daily Electrical Energy Gain from PV System

Maximum generation is in the summer months with a peak generation figure of 14.4kWh.

6.2.10 Electrical Load

A tabulation of the typical electrical loads in the building are given in Table 5.1 in Section 5.1.1. Major loads such as the stove and water heater are specified to use LPG fuel to reduce the required capacity of the Off-grid system. To estimate daily loads, typical appliance usage data is taken BRANZ [3]. This data is used to collate a comprehensive energy usage forecast. Figure 6.19 shows the projected daily energy usage over the period of one year.

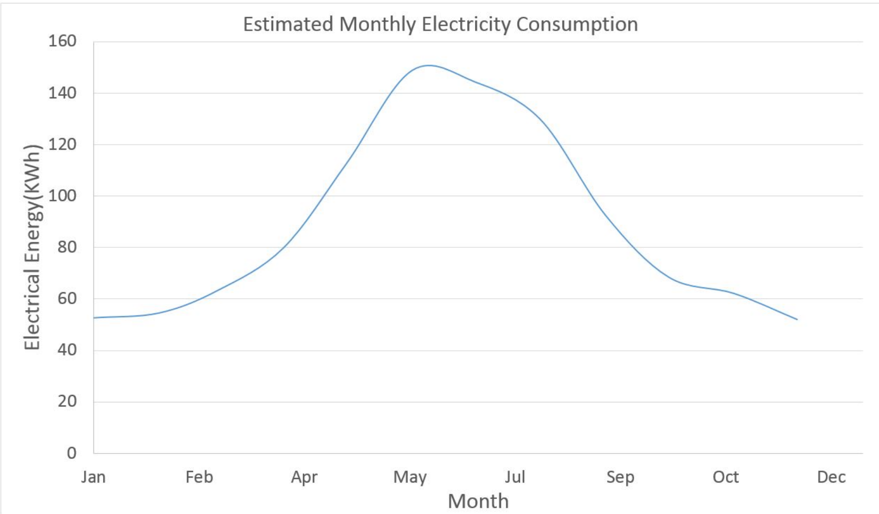


FIGURE 6.19: Estimated Monthly Electricity Consumption

The highest loads tend to be during the winter season due to occupant generally being indoors more of the day and less daylight hours. The highest energy usage for a single day was projected to be 5.4kWh. The average monthly energy usage is 93kWh. The above data does not include any space heating that may be required to cover deficit in the thermal system.

6.2.11 Electrical Energy Storage requirements

The electrical energy storage requirements for the system are dependent on the dynamic load and generation. Considering the short term requirements, the PV panels only generate during sunlight hours so storage is required to provide energy at night. In addition, storage is also required to provide the building with energy during extended periods of low solar resources. To satisfy these requirements, the storage system is designed around the worst possible scenario.

All calculations were done assuming the average monthly generation is sufficient to cover the average monthly load with excess. Electrical load due to thermal deficit was also included in the calculation. Figure 6.20 shows the simulated accumulated energy deficit as well as total generation and consumption.

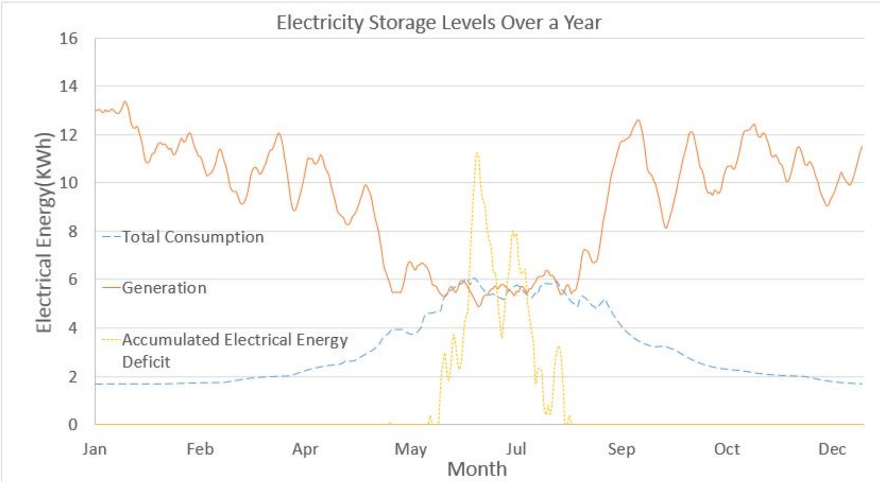


FIGURE 6.20: Simulated Electricity Storage Levels Over a Year

The minimum daily energy production for the year is 4.9kWh with a corresponding estimated daily energy consumption of 5.9kWh leaving a peak energy deficit of 1kWh. The maximum accumulated energy deficit throughout the year comes to 11.2kWh which is the minimum size the storage system would need to be to ensure an uninterrupted electricity supply.

The battery type specified in Section 5.1.3 is lead acid so the acceptable minimum state-of-charge is 50%. The battery pack is recommended to have a minimum rated capacity of 22.4kWh to meet the storage requirements of the off grid system. The Crown CR430 lead acid battery has been identified as the most cost effective storage device for this application. Eight of these batteries will make up a 48 Volt, 20.6kWh storage system which will mean the storage level will briefly fall below the recommended 50% level. In this particular case, the very small life reduction can be justified by the significantly lower cost.

6.2.12 Overall Energy Performance

With all aspects of the energy system considered, a year long simulation was run. The simulation tests whether the off-grid system can reliably provide consistent internal temperatures and electrical supply. Figure 6.21 shows the daily average internal temperature and the level of the storage system over one year.

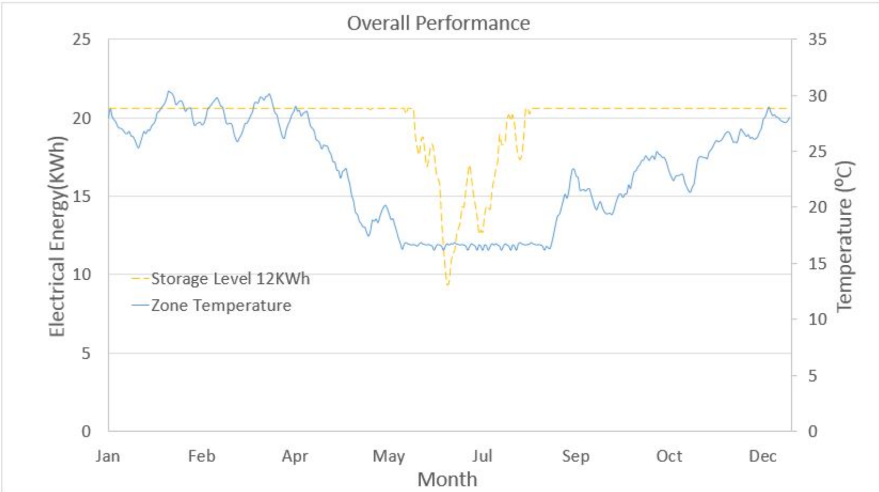


Figure 6.21: Overall Building Performance

The lowest state of charge recorded in the simulation is 46% which is 4% more than the recommend 50% minimum state of discharge. In exceptional situations, including emergencies it is possible to discharge the storage system further while only marginally decreasing the cycle life of the batteries. Thus, there is an ample backup supply should the requirement arise.

The average daily temperature remains between 16°C and 31°C which is above the minimum temperature of the zone but is higher than the maximum temperature set point of 25°C. The total thermal deficit energy is 93kWh over the year which is very low when compared to the heating load in a typical building of the same floor area.

6.2.13 Conclusion

Modelling the transportable building design in TRNSYS has provided insight in to the energy performance of the entire system. Interactions between the electrical and thermals system have been explored to gain a comprehensive outlook on the potential real world performance of the system.

The results have shown that the BIPV/T system is capable of supplying the building with 100% of its energy needs given that the battery pack is sufficiently sized to supply the building through extended periods of low solar resources. The thermal gain from the BIPV/T system is not able to supply all of the required thermal energy to keep the minimum zone temperature above 16°C. During Autumn and Winter an auxiliary resistive heater is included in the model to maintain the minimum zone temperature. This heater significantly increased the electrical load in the design which in turn increased the required electrical energy storage.

The results show that 12kWh of electrical energy storage is sufficient to ensure a reliable electricity supply to the building. The battery pack must be appropriately sized to ensure the state of charge does not fall below the recommended level for its respective chemistry. A Lead acid battery pack would require a rated capacity of at least 24kWh for the state of charge to stay above the recommended 50%. A lithium-ion battery pack would require a rated capacity of at least 12.7kWh for the state of charge to stay above the recommended 5%.

6.3 Building Cost Analysis

6.3.1 Cost Comparisons

There is currently no other complete standalone off grid building products so it is difficult to compare the building design in this project with other, already available, products. Only a breakdown of individual components can be priced to gain an accurate comparison.

Transportable Building The most similar standard products that are readily available are prefabricated timber framed buildings. These buildings come in a variety of shapes and sizes and are customisable to customers' requirements. They typically consist of a timber or steel base frame to provide strength for lifting with timber framed walls including a low cost cladding, insulation and plasterboard lining. Quotes from two different manufacturers of prefabricated transportable buildings are given as follows:

EPS Panel Systems $45,813.00

Cabins2Go $42,521.74

The buildings quoted are models with the closest dimensions to the building design in this project. Only the base buildings are quoted which include some fit out items where specified. Remaining fit out items are added to the base building costs to ensure all quote specifications are in agreeance. The fit out items added to each building quote are priced below. The prices are taken from Stonewood Resources.

Bathroom and Shower Fittings $2,328.17

Electrical Fitout $1,759.80

Fixed Appliances $1,424.00

Kitchen Joinery $2,294.78

Gas Fitout $2,563.02

Plumbing Fitout $1,872.53

OffGrid System There is now a market of Offgrid retrofitting in New Zealand as the price of the required equipment become competitive with the cost of installing a new Grid Connection in many cases. The Offgrid system in this comparison consists of an array of PV panels, Storage Battery Bank, Battery charging and management systems and an inverter. The compared systems are sized to cover the projected electrical load as well as simulated energy harvested by the PV thermal system as there is not currently a system available in New Zealand that provides BIPV/T capability. The price for an all-in-one package that is available on the market is:.

Solar Electric Technology $28,510.00

Awning and Carport The awning and carport are integrated in to the building design in this project, but the available transportable buildings on the market do not provide this option. Awnings and carports will be priced separately with typical building techniques. Prices for commercially available Carports and Awnings are:

Bunnings - Prepainted Steel Carport $2,446.50

Kitset - ColorSteel Carport $2,950.00

Kitset - ColorSteel Awning $1,450

Ventilation System The counter crossflow heat exchanger system described in Section 2.4 is already an available product on the market and is generally marketed as a 'Heat Recovery System'. Quoted costs for two different retrofitted systems are:

DVS $1500.00

HRV $1600.00

6.3.2 Cost Analysis

Appendix D shows a spreadsheet with a complete itemisation of cost for the building design. All pricing shown is as per Stonewood's trade costs and does not include any margin. Costs have also been itemised on the assumption that the prototype cost would be significantly higher than the cost to mass manufacture the building. Labour costs are significantly reduced for the mass manufactured estimate with a total manufacture cost of $90,906.05 compared to a prototype cost of $96,110.70.

Adding Stonewood's typical margin of 20% and 15% GST yields a sale price of $125,450.36 for the mass manufactured product. The total materials cost for a complete building using the already available products outlined in Section 6.3.2 is $91,619. Labour to assemble the already available products is estimated at $10,000 bringing the total cost of the alternative system to $101,619.

The alternative system costs are lower than the estimated cost of the building design in this project, because there are fundamental performance differences of the compared systems. While the compared products have specifications as close as possible to the building design in this project, the thermal performance of these products would be significantly lower due to the lack of thermal mass. The benefit of water storage cannot be costed for the products as it can only be building integrated and is not a currently available option.

6.3.3 Pay Back Period

The off-grid energy system carries a large upfront capital cost when compared with a readily available grid connection. While off-grid systems primarily target sites that do not have a readily available grid connection, it is still useful to calculate the pay back period of the system to get a gauge of its economic performance.

The total cost for the off grid system including a 20% margin and 15% GST was estimated at $33,229.79. Assuming a flat rate grid energy cost of 24c/kWh, a yearly line charge of $288, and that thermal energy for the BIPV/T system would have otherwise been an electrical load, the yearly return from the off grid system was estimated to be $812. The payback period for the system would be approximately 40 years.

6.3.4 Commercial Viability

The above comparison does not provide a definitive analysis of the viability of the design as the specifications are not exactly the same. The comparison does offer promise that the building could have commercial potential as the thermal and therefore electrical performance of the building is superior to compared products as well as the overall cost estimate being lower. Due to the specialised nature of the design, confirmation of commercial viability hinges almost entirely on the experience provided by Brent Mettrick. Brent has more than 30 years' experience in the building industry and has a very good 'feel' of what will and what will not succeed in the market place. A final design meeting was conducted by Brent Mettrick to review the cost estimate. He was confident that the design has commercial potential and that it would be a saleable product. It was identified that the product would cater to not only 'Green' aware clients but would also offer a significant incentive to customers that would otherwise be paying for grid connection costs on their chosen site.

6.3.5 Conclusion

The build cost of the final design has been estimated at $90,906.05 excluding GST. As there are no direct competitors on the market, the building costing was compared to packages made up of commercially available products. The lowest estimate of an already available product came to $101,619, $23,831 lower that the estimate for the building design in this project.

Comparing the cost estimate of the building design to packages comprised of commercially available products has given assurance that the design costing is at an acceptable level. The outcome of the comparison is that costing can be identified as being reasonable although a firm decision on its commercial viability can not be made from these numbers. Brent Mettrick is confident that the building could be successful as a commercial product.

Chapter 7

Conclusions

In this project, the design and analysis of an Energy Positive, Modular, Transportable Building has been carried out. The design has progressed through multiple stages to arrive at a solution that satisfies performance targets while still retaining aesthetic appeal.

An experimental apparatus was constructed and used to test the performance of a BIPV/T system that is currently in use in Dennis Chapman's Eco-Castle. Air was circulated in a closed system beneath the solar panel and through an air to water heat exchanger to measure the exact quantity of thermal energy being extracted. Air flow beneath the panel was varied while thermal output was monitored to optimise the net thermal energy output of the system. The system was able to achieve a 53% maximum combined electrical and thermal efficiency. A secondary apparatus was constructed using the same solar panel but with the rear of the panel naturally ventilated. This system achieved a higher electrical efficiency showing that enclosing the rear of the panels in BIPV/T system had a negative effect on electrical efficiency.

The initial design of the building utilised almost exclusively Conqueror Structural Insulated Panels as a building material. This initial design was run through preliminary modelling that identified that the performance would be satisfactory but after consultation with Stonewood executives, it was seen that the aesthetics of the design would not be satisfactory for the commercial product. The downfall of the Conqueror Panel system was the painted steel interior walls that would acceptable in a residential home. The fixing of plaster board to the interior walls was investigated but was deemed unacceptable by the Conqueror Panel manufacturer.

The final building design utilises the Versipanel Structural Insulated Panel system for the walls of the building with Conqueror panels being retained for the roof. The fibre cement outer skins of the Versipanel system satisfied the interior aesthetic issue as they can be plastered and painted to give the same feel as a traditional plaster board finish.

TRNSYS was used to build a comprehensive model of the final design to analyse its thermal and electrical performance. For eight months of the year the building is able to self-regulate the internal zone temperature with the use of the building integrated thermal system. A resistive auxiliary heater is used to maintain a minimum of 16°C during the remaining four months. The increased thermal mass, in the building, was found to significantly damp temperature fluctuations in the building which aided the thermal system in maximising harvested solar thermal energy. The model showed that the building is capable of being energy positive. A minimum of 11.2kWh of electrical storage was required to maintain a reliable electricity supply through times of extended low solar resources.

A cost analysis was performed on the building to investigate the design's viability in the market place. The complete contruction cost for the design excluding GST was $90,906.05. No other directly comparable all-in-one systems are currently available on the market so comparisons were made to packages that were made up of commercially available products that would closely resemble the design in this project. The cheapest of these packages came to $101,619 which is significantly lower than the completed costing of the design in this project. As the comparisons were not of completely integrated packages, a definitive confirmation of viability was not provided. Brent Mettrick is confident that the building design could be successful in the market place.

7.1 Future Work

7.1.1 Construction, Testing and Commercialisation

To confirm the accuracy of the TRNSYS model, a test building should be constructed and instrumented to data log the real world performance. The primary goal of the testing would be to validate the thermal and electrical performance of the building throughout the winter months as it is in this period that the system is pushed to its limits.

With testing completed, the data could be analysed to determine if the building is under or over performing and adjustments to the design could be made to more closely achieve the design specifications.

With real world data to confirm the performance of the design, the building could be marketed as an all-in-one Transportable building that is entirely self-sustaining.

Bibliography

[1] Olympia Zogou and Herricos Stapountzis. Experimental validation of an improved concept of building integrated photovoltaic panels. *Renewable Energy*, 36(12):3488 – 3498, 2011. ISSN 0960-1481.

[2] José Fernández-Seara, Rubén Diz, Francisco J. Uhía, Alberto Dopazo, and José M. Ferro. Experimental analysis of an air-to-air heat recovery unit for balanced ventilation systems in residential buildings. *Energy Conversion and Management*, 52 (1):635 – 640, 2011. ISSN 0196-8904.

[3] BRANZ New Zealand. Energy use in new zealand households - report on the 10 year analysis for the household energy and end-use project (heep), 2006. URL `http://www.branz.co.nz/cms_show_download.php?id=b1ab61dd06f50e83e6a184b29b68a989472502ed`.

[4] Ruolang Zeng, Xin Wang, Hongfa Di, Feng Jiang, and Yinping Zhang. New concepts and approach for developing energy efficient buildings: Ideal specific heat for building internal thermal mass. *Energy and Buildings*, 43(5):1081 – 1090, 2011. ISSN 0378-7788. Tackling building energy consumption challenges - Special Issue of ISHVAC 2009, Nanjing, China.

[5] Soteris A. Kalogirou, George Florides, and Savvas Tassou. Energy analysis of buildings employing thermal mass in cyprus. *Renewable Energy*, 27(3):353 – 368, 2002. ISSN 0960-1481.

[6] Building Research Establishment UK Ltd. Passivhaus primer: Introduction an aid to understanding the key principles of the passivhaus standard, 2011. URL `http://www.passivhaus.org.uk/filelibrary/Primers/KN4430_Passivhaus_Primer_WEB.pdf`.

[7] Yuxiang Chen, A.K. Athienitis, and Khaled Galal. Modeling, design and thermal performance of a bipv/t system thermally coupled with a ventilated concrete slab in a low energy solar house: Part 1, bipv/t system and house energy concept. *Solar Energy*, 84(11):1892 – 1907, 2010. ISSN 0038-092X.

[8] Jin-Hee Kim, Se-Hyeon Park, Jun-Gu Kang, and Jun-Tae Kim. Experimental performance of heating system with building-integrated photovoltaic thermal (bipvt) collector. *Energy Procedia*, 48:1374 – 1384, 2014. ISSN 1876-6102. Proceedings of the 2nd International Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2013).

[9] Standards New Zealand. *NZS 4214:2006 - Methods of determining the total thermal resistance of parts of buildings.*

[10] Crown Battery Manufacturing Company. *CR430 Data Sheet*, 2013. URL `http://www.yhipower.co.nz/downloadhandler.axd?type=2&id=100100&ins=1`.

[11] Hy-Tech Solar. Hybrid solar storage systems, 2015. URL `http://www.goingsolar.com.au/what-we-do/solar-electricity-hybrid`.

[12] Grundfos Commercial Building Services. Counter cross flow heat exchanger, 2015. URL `http://cbs.grundfos.com/india/lexica/AC_Cross_flow_heat_exchanger.html#-`.

[13] John A. Duffie and William A. Beckman. *Solar engineering of thermal processes.* Wiley, Hoboken, N.J, 3rd edition, 2006. ISBN 9780471698678;0471698679;.

Appendix A

PV Panel Data Sheet

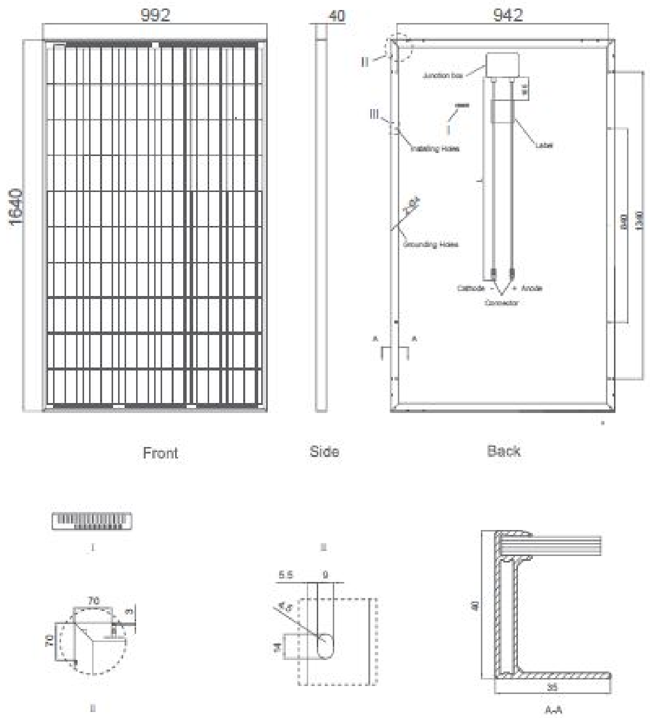
SPECIFICATIONS

Module Type	TP-245P		TP-250P		TP-255P		TP-260P		TP-265P	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	245Wp	181Wp	250Wp	184Wp	255Wp	189 Wp	260Wp	193Wp	265Wp	197Wp
Maximum Power Voltage (Vmp)	30.1V	27.8V	30.5V	28.0V	30.8V	28.5V	31.1V	28.7V	31.4V	29.0V
Maximum Power Current (Imp)	8.14A	6.50A	8.20A	6.56A	8.28A	6.63A	8.37A	6.71A	8.44A	6.78A
Open-circuit Voltage (Voc)	37.5V	34.8V	37.7V	34.9V	38.0V	35.2V	38.1V	35.2V	38.6V	35.3V
Short-circuit Current (Isc)	8.76A	7.16A	8.85A	7.21A	8.92A	7.26A	8.98A	7.31A	9.03A	7.36A
Module Efficiency STC (%)	14.97%		15.27%		15.58%		15.89%		16.19%	
Operating Temperature(℃)	-40℃~+85℃									
Maximum system voltage	1000VDC (IEC)									
Maximum series fuse rating	15A									
Power tolerance	0~+3%									
Temperature coefficients of Pmax	-0.41%/℃									
Temperature coefficients of Voc	-0.31%/℃									
Temperature coefficients of Isc	0.06%/℃									
Nominal operating cell temperature (NOCT)	45±2℃									

STC: Irradiance 1000W/m² Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

Engineering Drawings

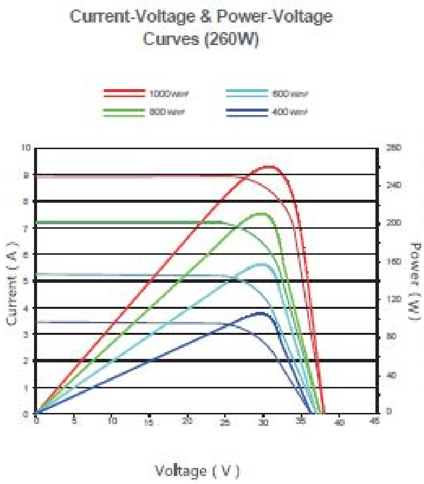


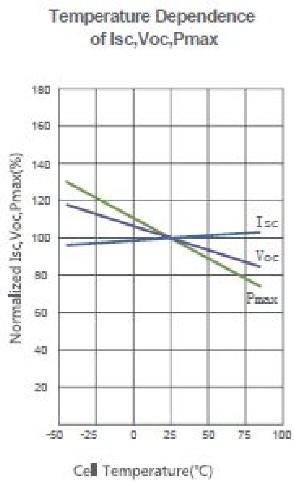
Packaging Configuration

(Two boxes=One pallet)

25pcs/ box, 50pcs/pallet, 700 pcs/40'HQ Container

Electrical Performance & Temperature Dependence





Mechanical Characteristics

Cell Type	Poly-crystalline 156×156mm (6 inch)
No.of cells	60 (6×10)
Dimensions	1640×992×40mm(64.57×39.05×1.57inch)
Weight	19.0 kg (41.9 lbs)
Front Glass	3.2mm, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminium Alloy
Junction Box	IP67 Rated
Output Cables	TÜV 1×4.0mm², Length:900mm

Appendix B

Battery Cost Comparison

Crown CR430 6V 430Ah Deep Cycle Lead Acid

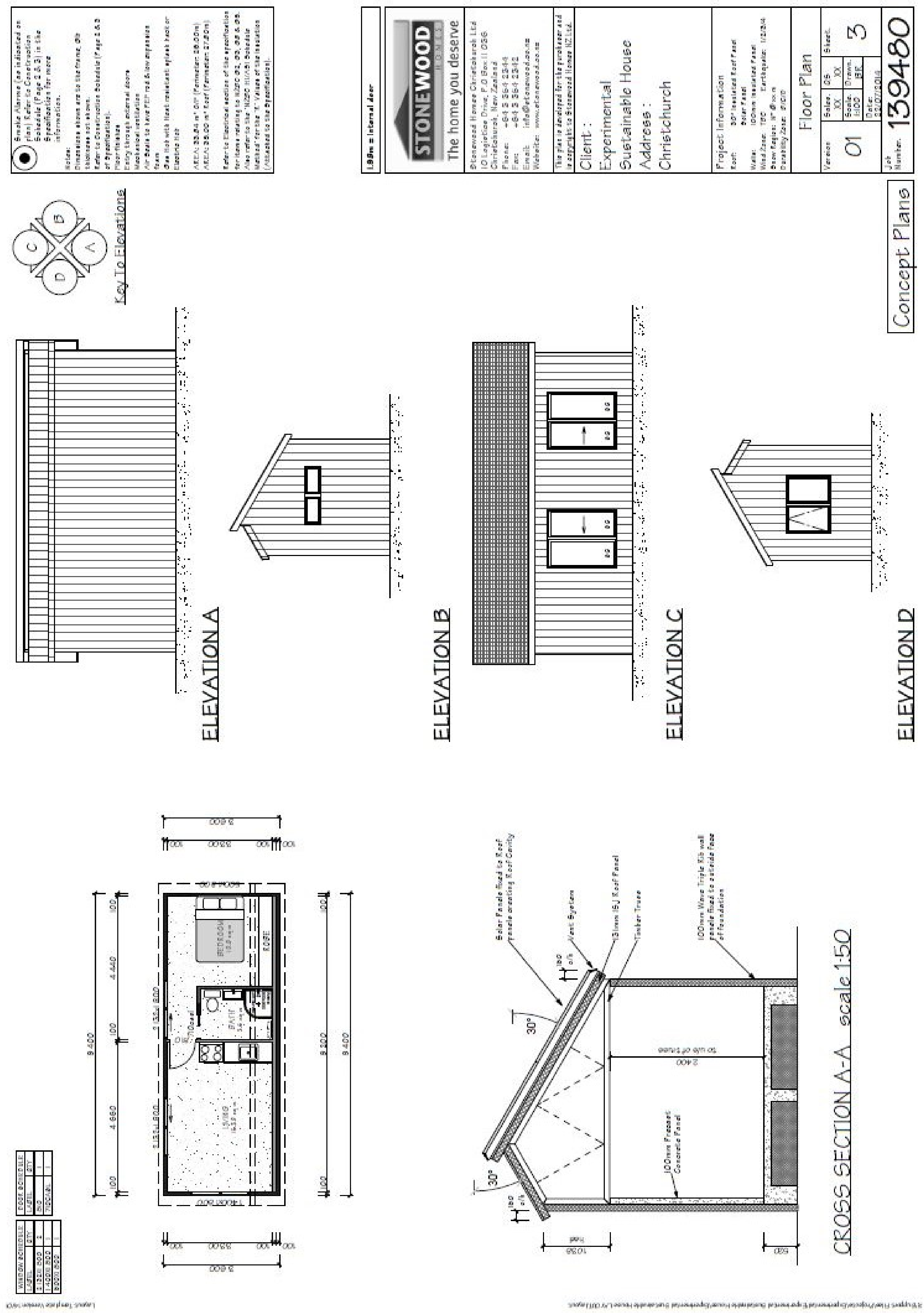
Number of batteries required	8		
Pack capacity	20.6	kWh	
Cost per battery	$580		(bestbatteries.co.nz)
Cost per pack	$4,640		
Expected cycle life	1200		(%50 depth of discharge)
Estimated lifespan (when correctly serviced)	15	years	
Cost per 10 years	$3,093.33		

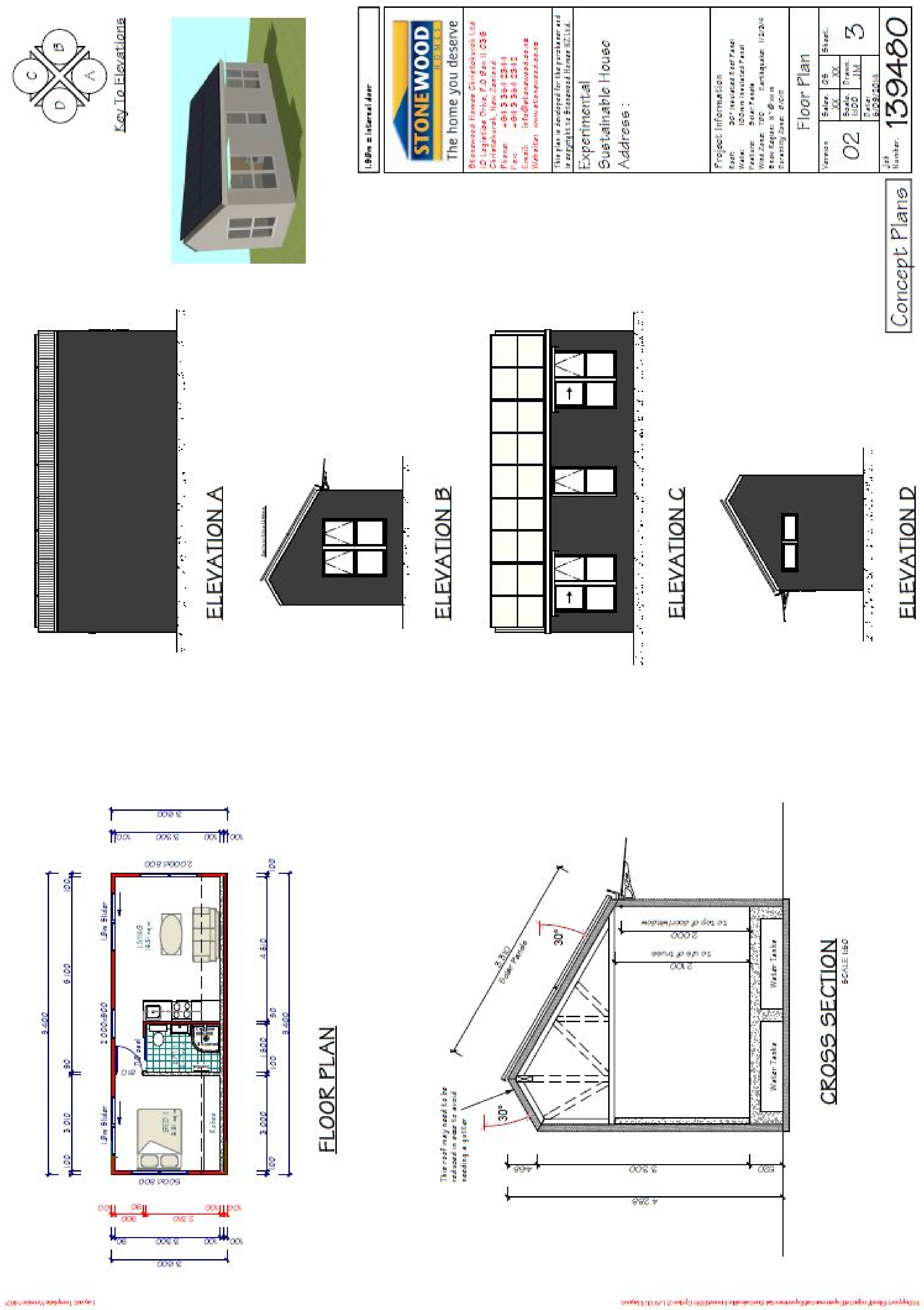
Sinopoly LITH-AA-SN-300AHA 12V 300Ah Lithium Iron Phosphate

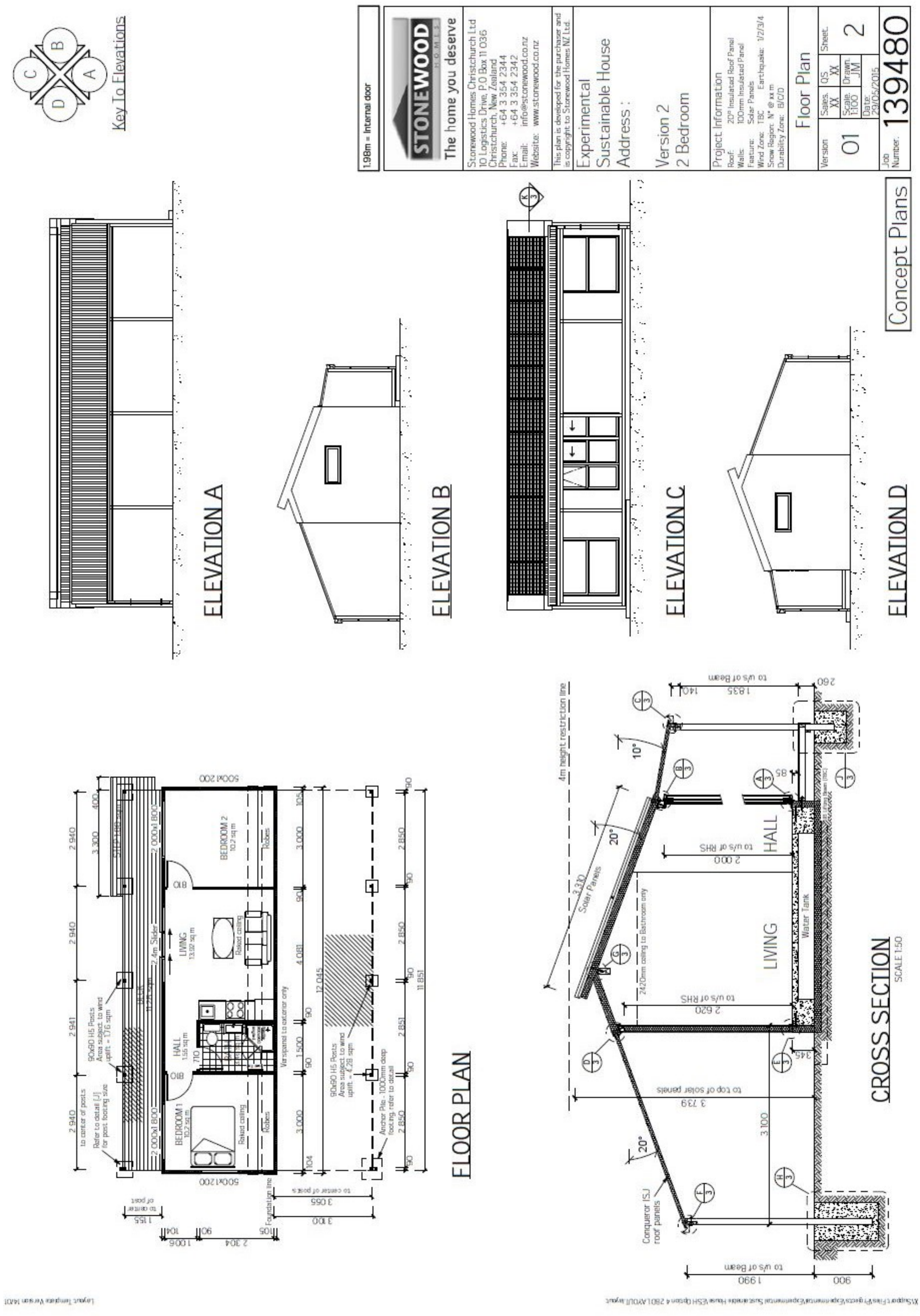
Number of batteries required	4		
Pack capacity	14.4	kWh	
Cost per battery	$3,420		(aasolar.co.nz)
Cost per pack	$13,680		
Expected cycle life	2000		(%80 depth of discharge)
Estimated lifespan	30	years	
Cost per 10 years	$4,560		

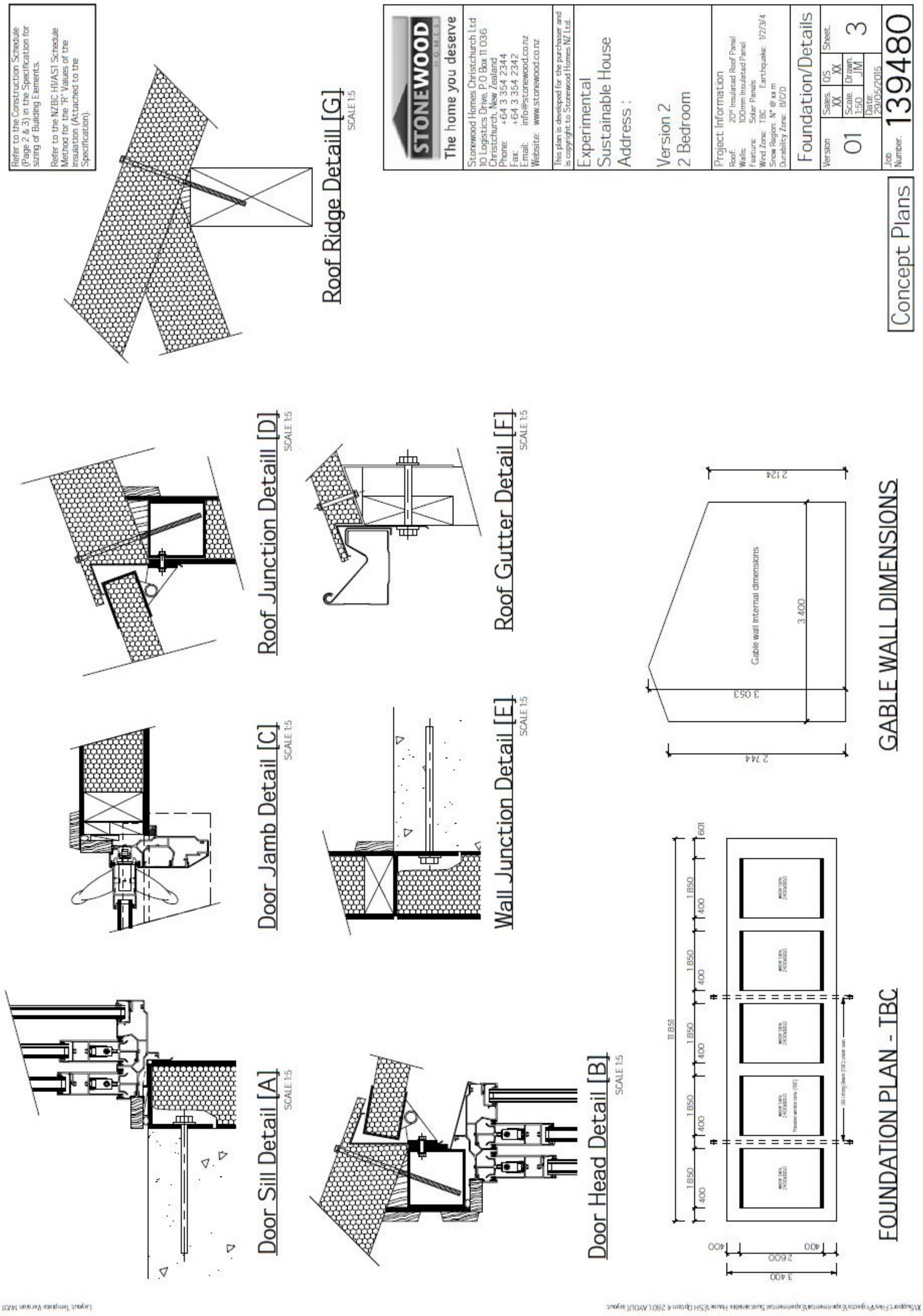
Appendix C

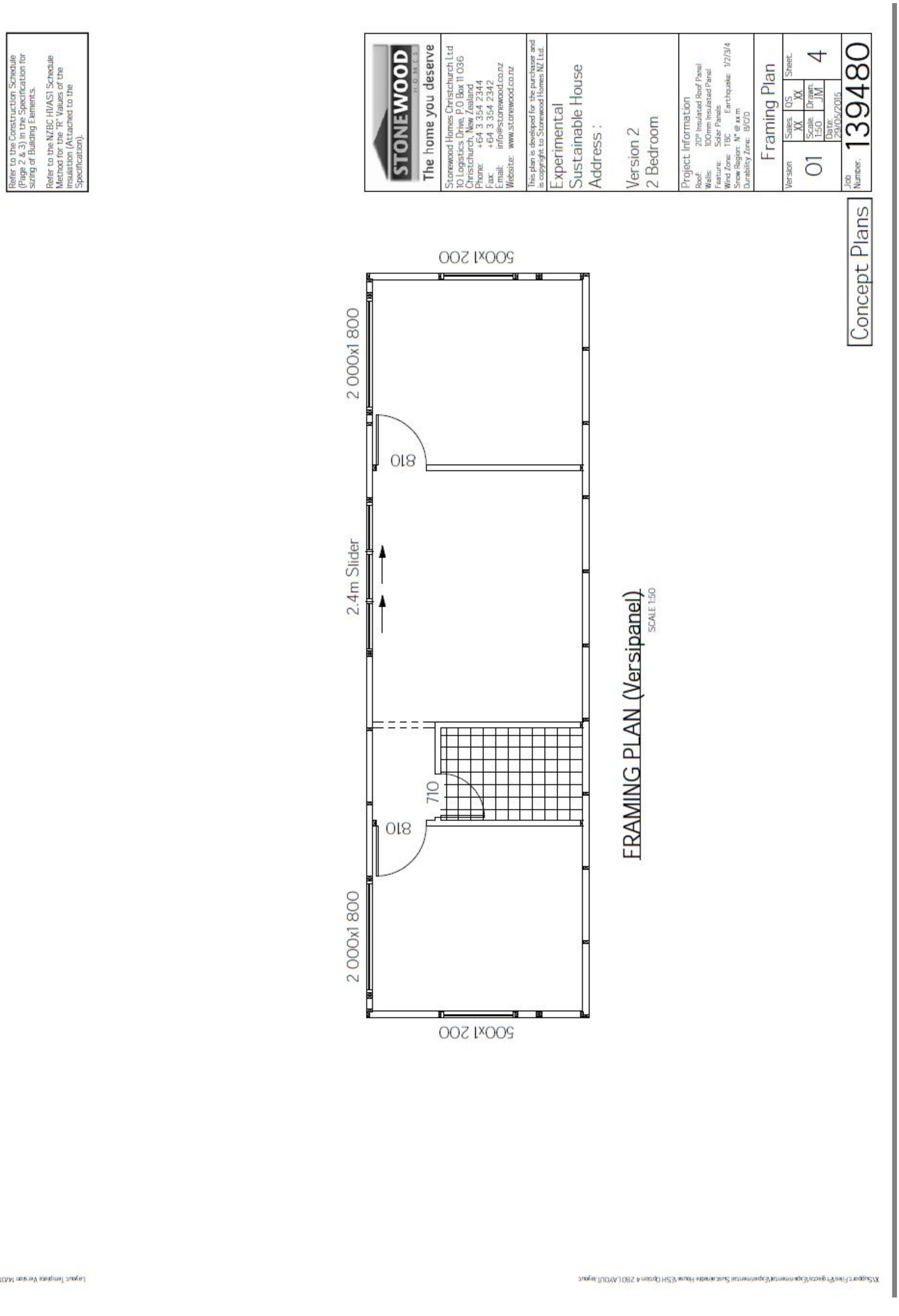
Building Concept Drawings

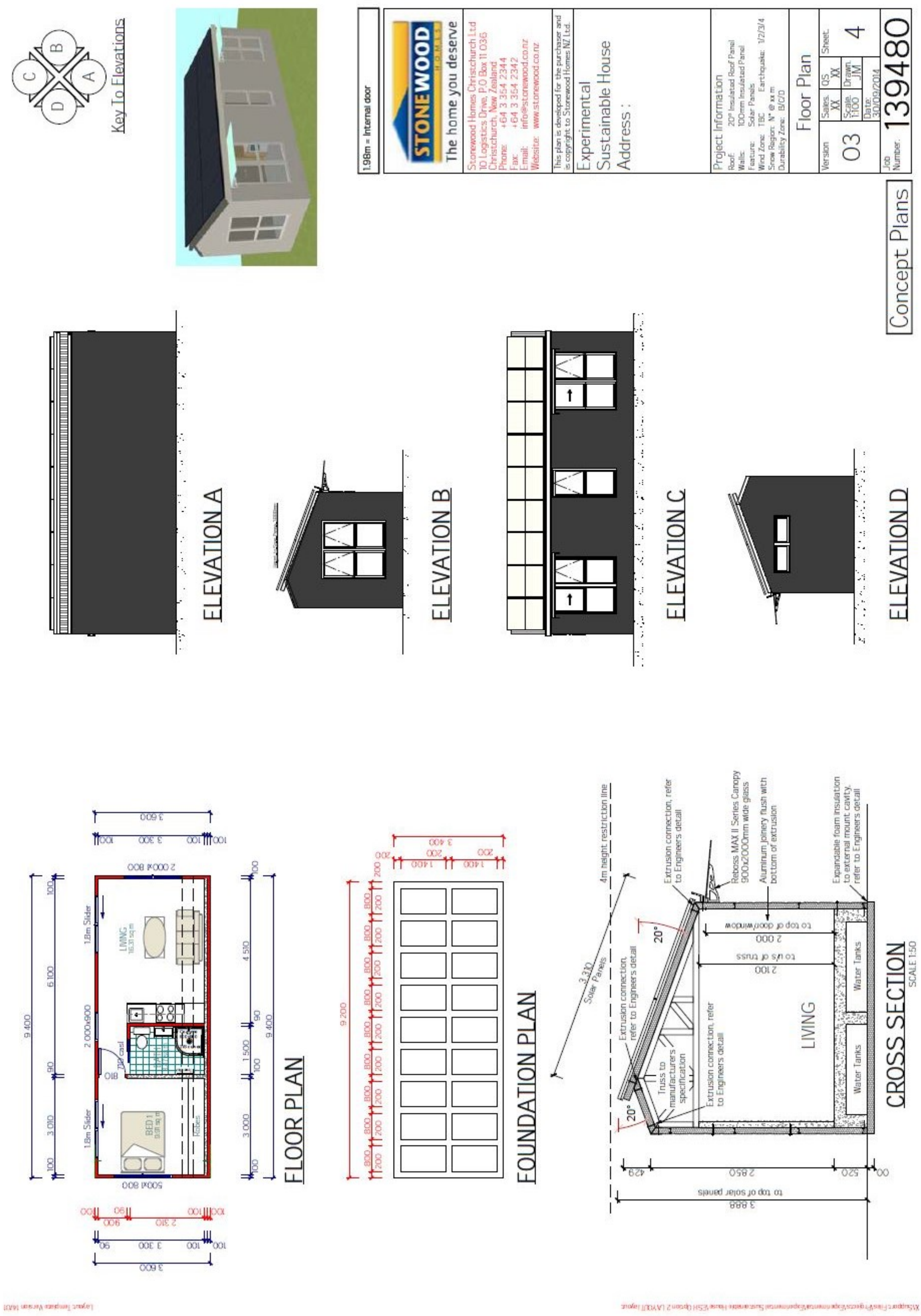

ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
Key To Elevations
CROSS SECTION A-A scale 1:50
STONEWOOD HOMES
The home you deserve
Client :
Experimental
Sustainable House
Address :
Christchurch
Floor Plan
139480
Concept Plans

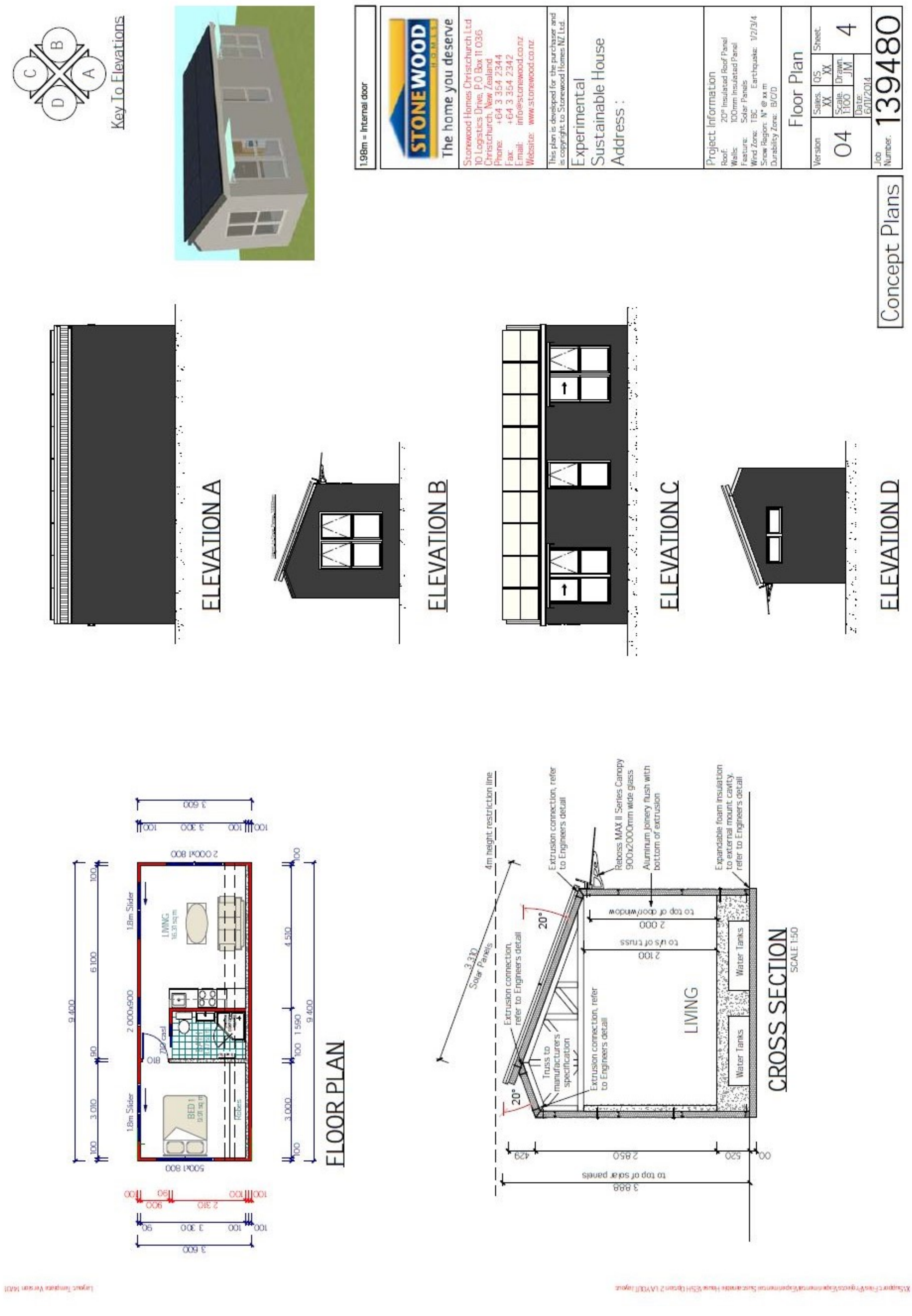

Key To Elevations
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
CROSS SECTION
STONEWOOD
The home you deserve
Experimental
Sustainable House
Address :
Project Information
Floor Plan
02
3
139480
Concept Plans

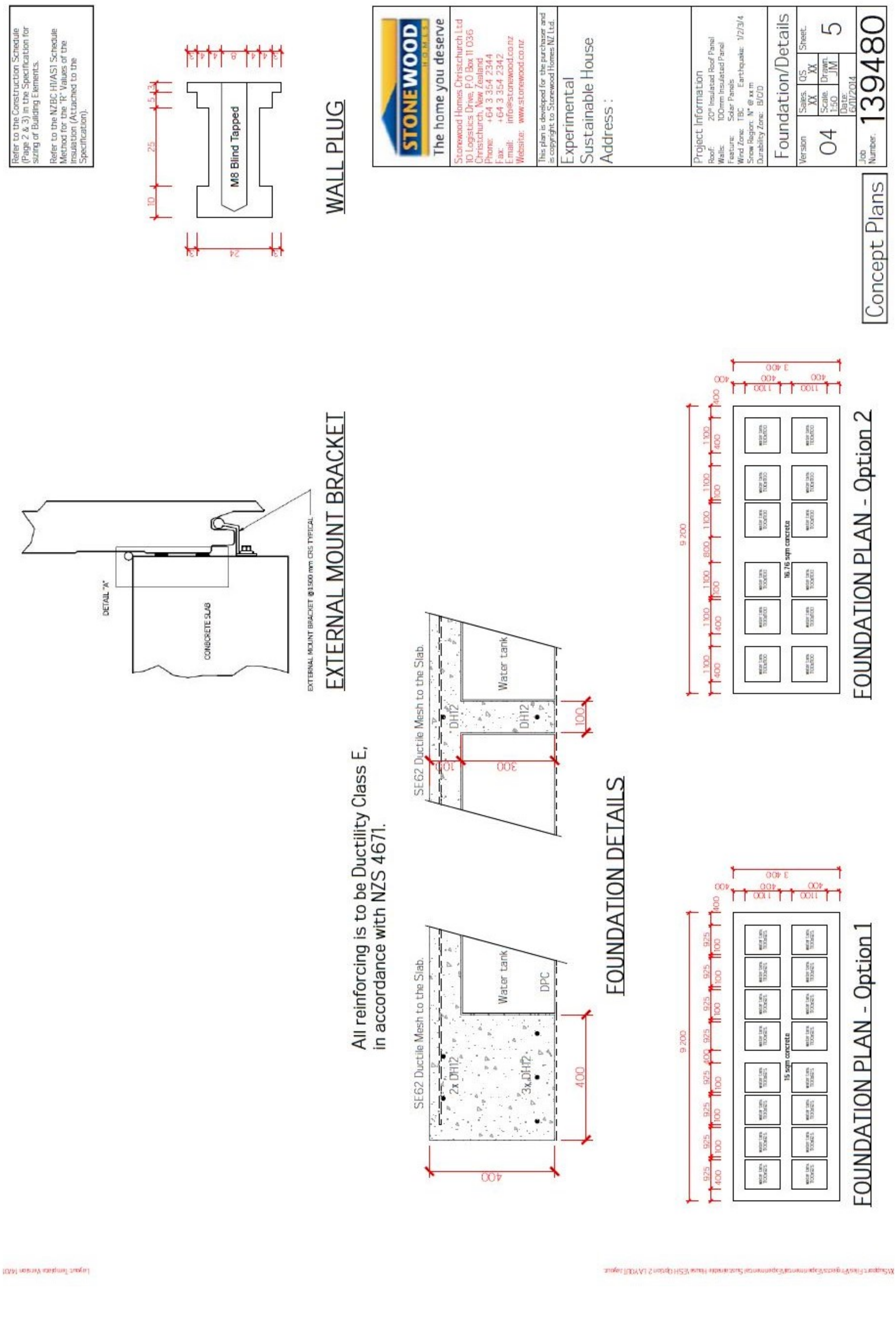

Key To Elevations
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
CROSS SECTION
SCALE 1:50
1.98m = Internal door
STONEWOOD
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Experimental
Sustainable House
Address :
Version 2
2 Bedroom
Project Information
Floor Plan
Concept Plans
139480
LIVING
HALL
BEDROOM 1
BEDROOM 2
Solar Panels
Water Tank
4m height restriction line


Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the Insulation (Attached to the Specification).
Roof Ridge Detaill [G]
SCALE 1:5
STONEWOOD
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Version 2
2 Bedroom
Project Information
Roof: 20" Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Foundation/Details
Version 01
Sales QS XX XX
Sheet 3
Scale 1:50
Drawn JM
Date 29/05/2015
Job Number 139480
Concept Plans
Roof Junction Detaill [D]
SCALE 1:5
Roof Gutter Detaill [F]
SCALE 1:5
Door Jamb Detaill [C]
SCALE 1:5
Wall Junction Detaill [E]
SCALE 1:5
Door Sill Detaill [A]
SCALE 1:5
Door Head Detaill [B]
SCALE 1:5
Gable wall internal dimensions
2 124
3 400
3 063
2 744
GABLE WALL DIMENSIONS
11 851
400
1 850
601
2 600
3 400
FOUNDATION PLAN - TBC

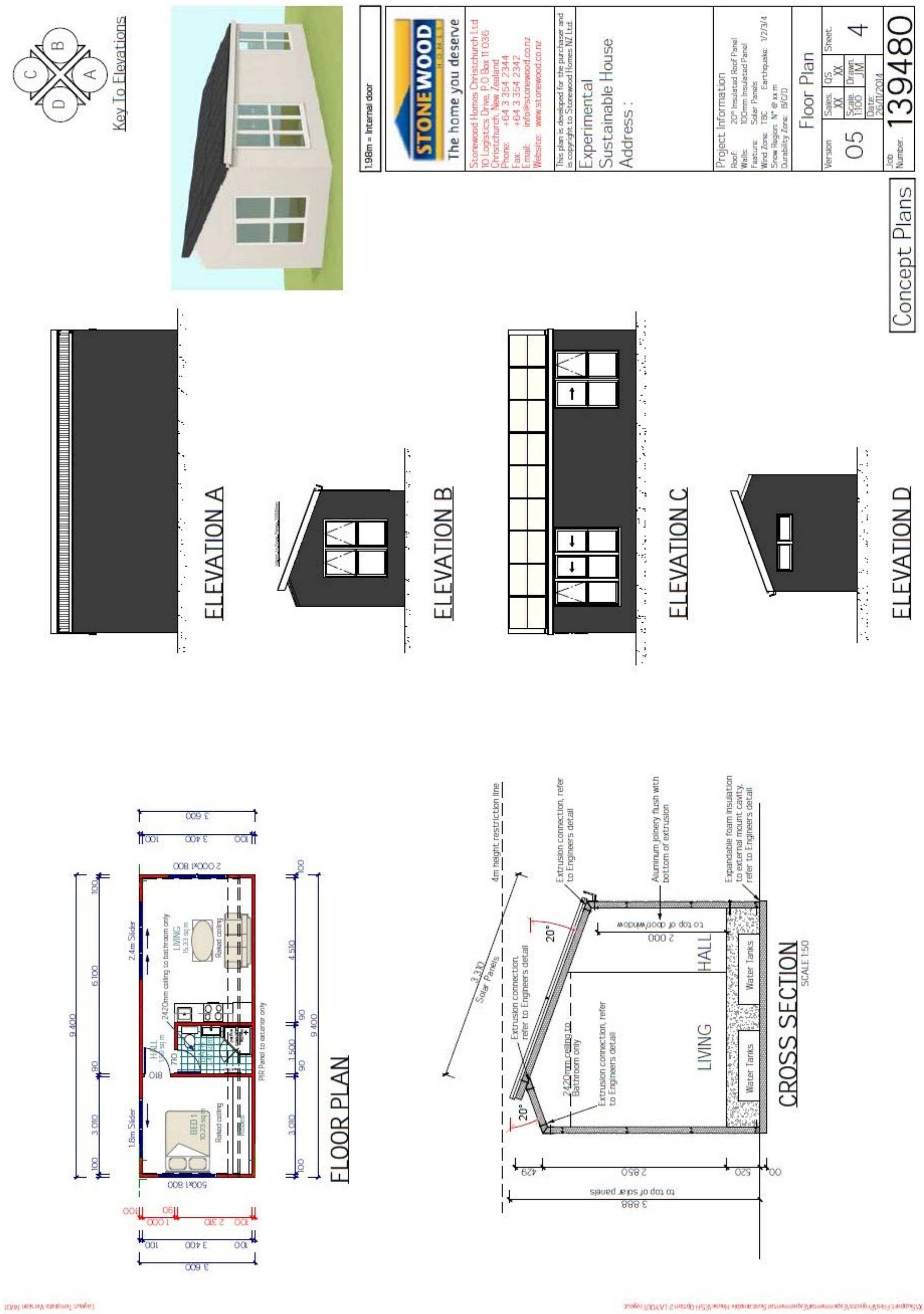

Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the 'R' Values of the Insulation (Attached to the Specification).
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Version 2
2 Bedroom
Project Information
Framing Plan
Version 01
Sheet 4
Scale 1:50
Drawn JM
Date 29/05/2015
Job Number 139480
Concept Plans
500x1 200
2 000x1 800
810
2.4m Slider
710
810
2 000x1 800
500x1 200
FRAMING PLAN (Versipanel)
SCALE 1:50

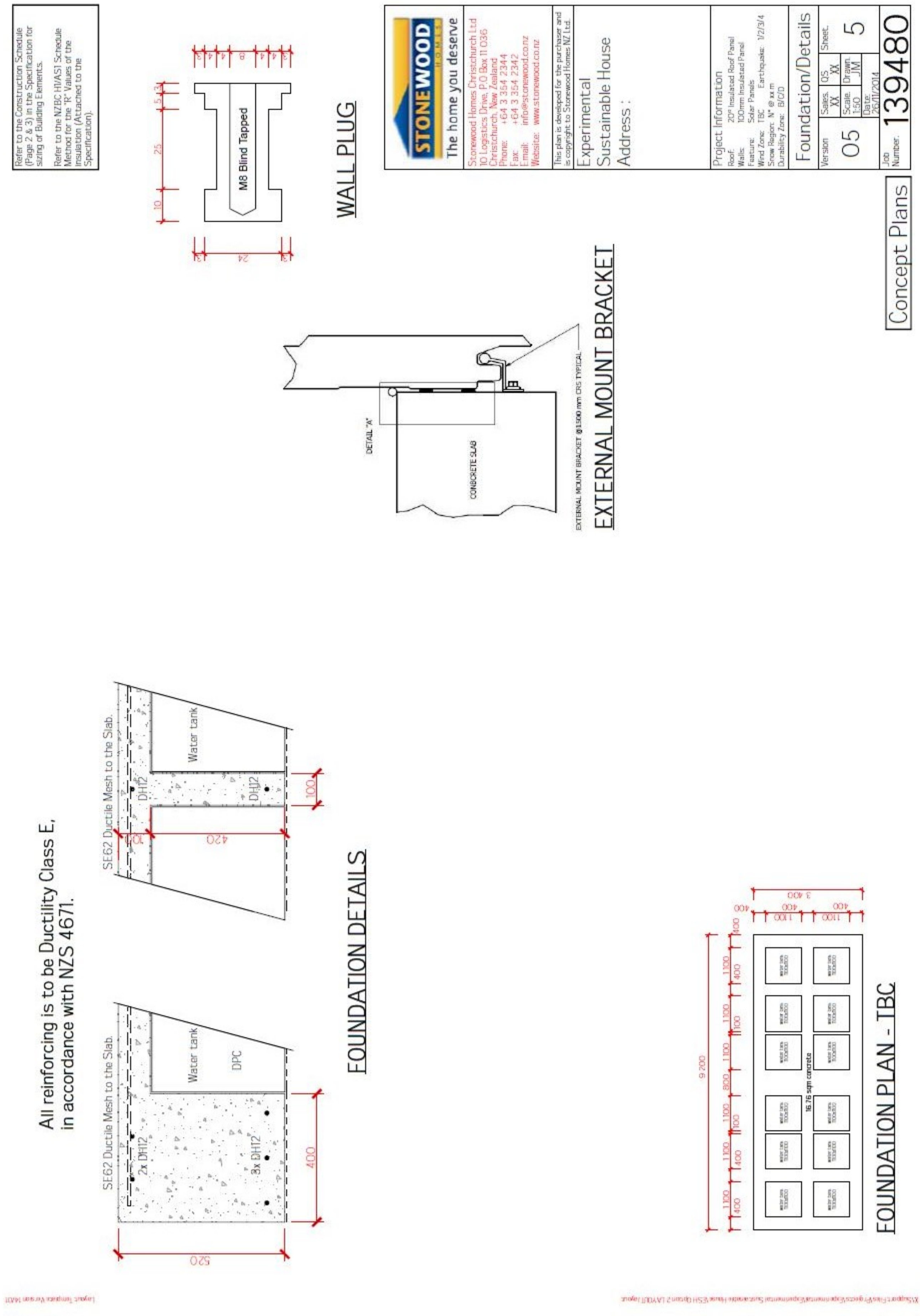

Key To Elevations
1.98m = Internal door
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental Sustainable House
Address :
Project Information
Floor Plan
Version 03
Sheet: 4
Date: 30/09/2014
Job Number: 139480
Concept Plans
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
FOUNDATION PLAN
CROSS SECTION
SCALE 1:50
LIVING
BED 1
1.8m Slider
Water Tanks
4m height restriction line
Solar Panels

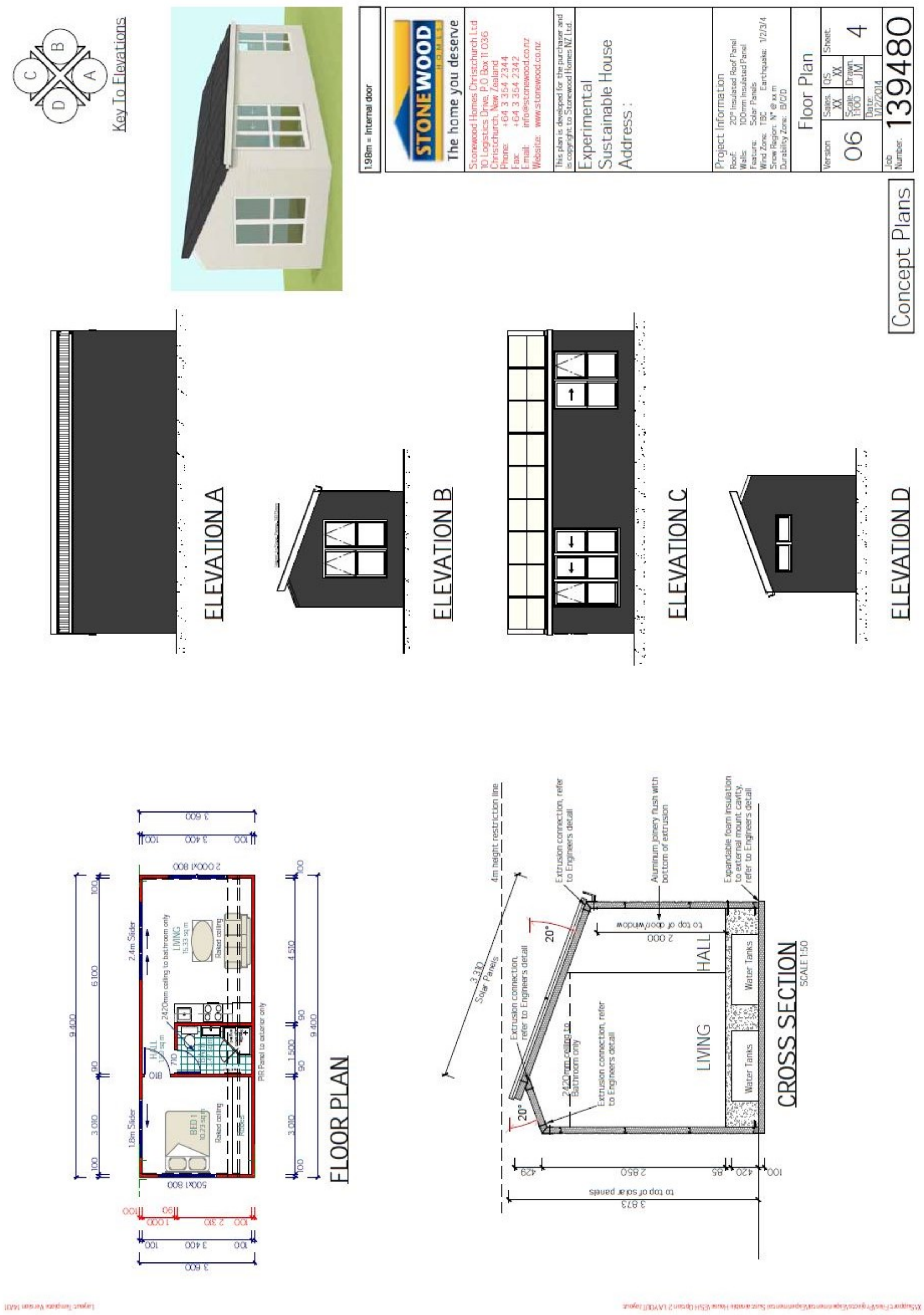

Key To Elevations
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
CROSS SECTION
SCALE 1:50
LIVING
Water Tanks
STONEWOOD
The home you deserve
Experimental
Sustainable House
Address :
Project Information
Floor Plan
Concept Plans
04
4
139480
1.98m = Internal door

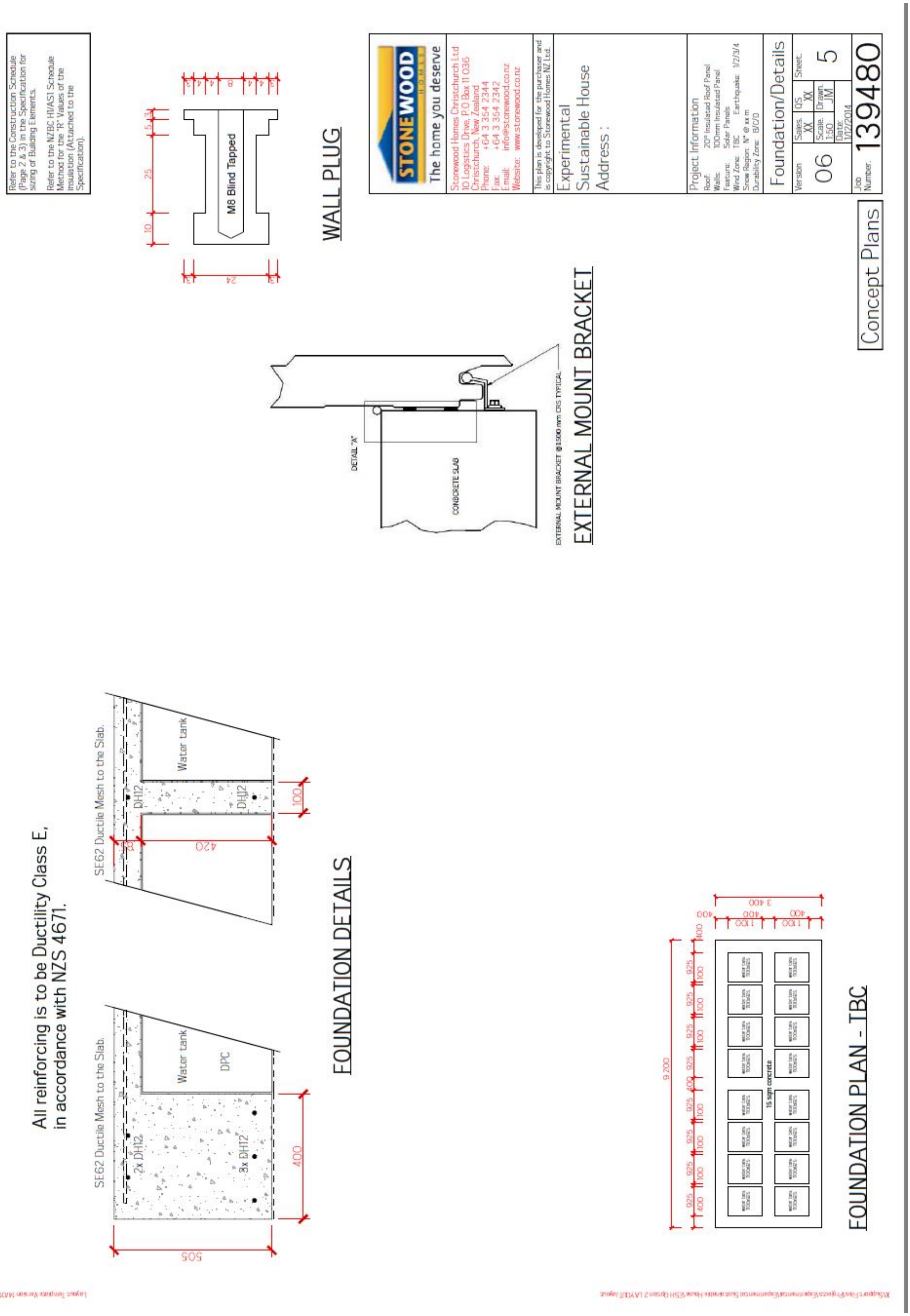


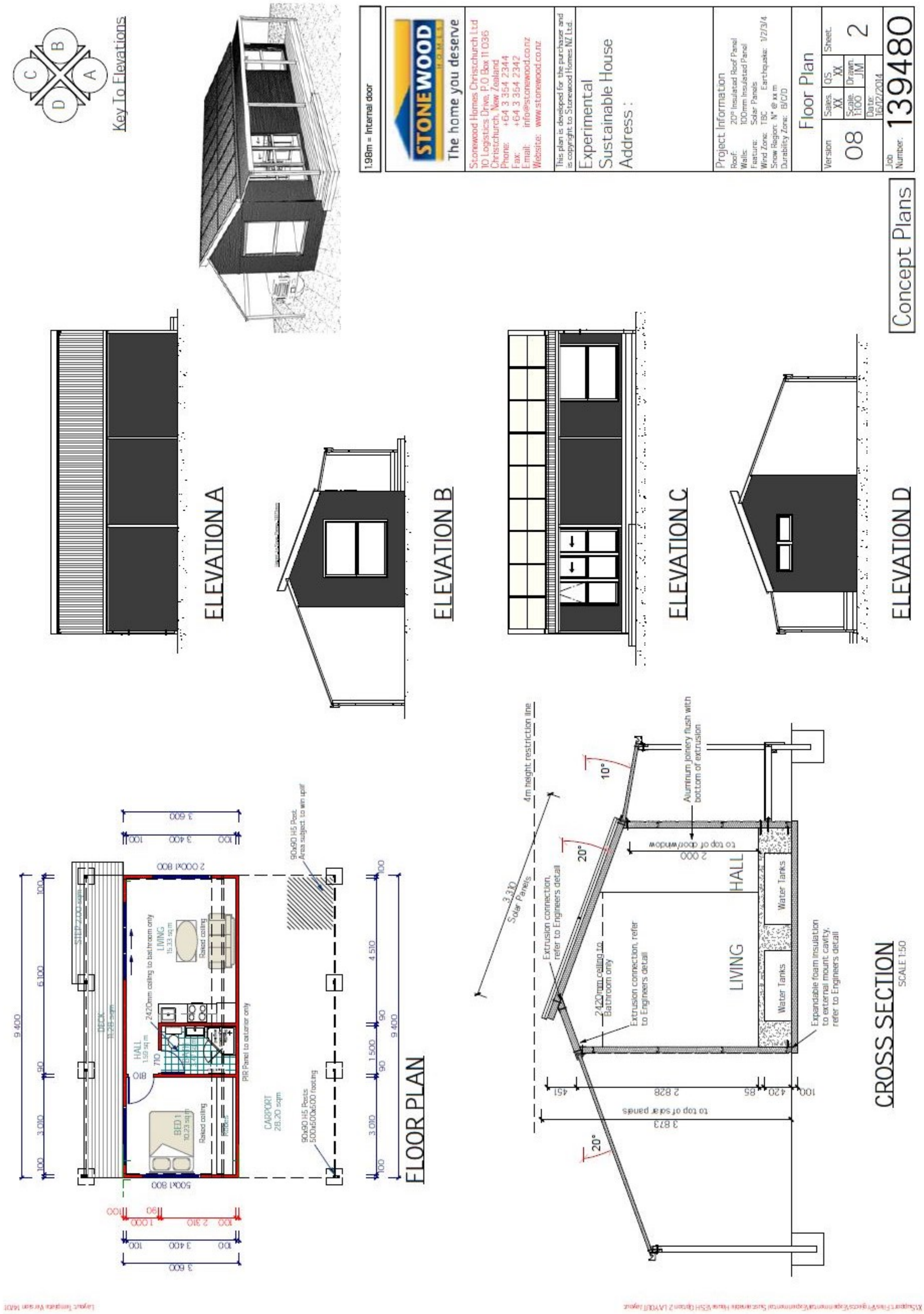
Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the Insulation (Attached to the Specification).
M8 Blind Tapped
WALL PLUG
DETAIL "A"
CONCRETE SLAB
EXTERNAL MOUNT BRACKET @1500 mm CRS TYPICAL
EXTERNAL MOUNT BRACKET
All reinforcing is to be Ductility Class E, in accordance with NZS 4671.
SE62 Ductile Mesh to the Slab.
2x DH12
3x DH12
Water tank
DPC
DH12
FOUNDATION DETAILS
15 sqm concrete
FOUNDATION PLAN - Option 1
16.76 sqm concrete
FOUNDATION PLAN - Option 2
STONEWOOD
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Project Information
Roof: 20" Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Foundation/Details
Version 04
Sales: XX
QS: XX
Scale: 1:50
Drawn: JM
Date: 6/11/2014
Sheet: 5
Job Number: 139480
Concept Plans

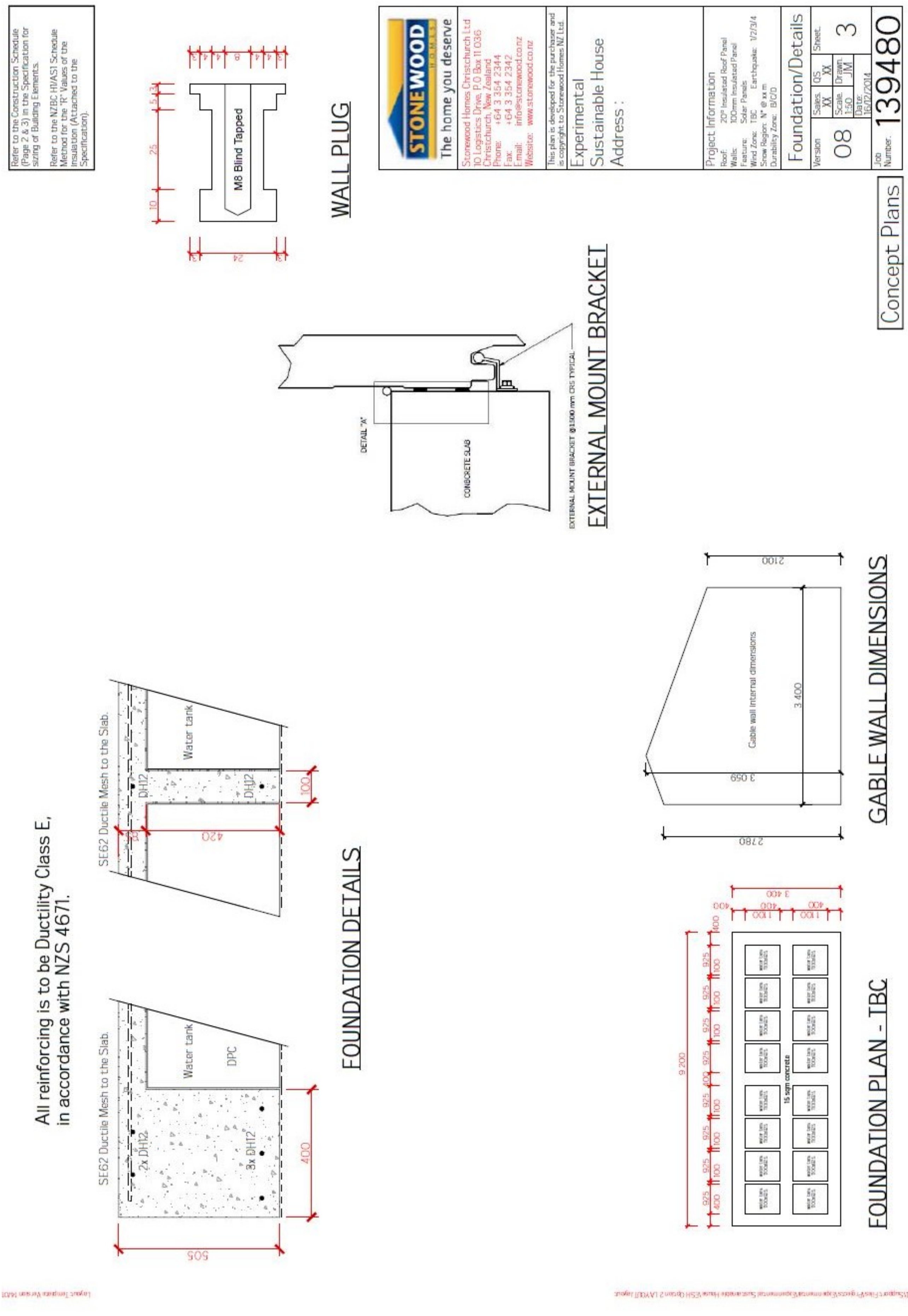

Key To Elevations
A
B
C
D
1.98m = Internal door
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
E.mail: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental Sustainable House
Address :
Project Information
Roof: 20° Insulated Roof Panel
Walls: 100mm Insulated Panel
Features: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Floor Plan
Version 05
Sales XX
QS XX
Sheet 4
Scale 1:100
Drawn JM
Date 26/11/2014
Job Number 139480
Concept Plans
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
LIVING
HALL
BED 1
2.4m Slider
1.8m Slider
2420mm ceiling to bathroom only
Raked ceiling
PIR Panel to exterior only
CROSS SECTION
SCALE 1:50
4m height restriction line
Solar Panels
Extrusion connection, refer to Engineers detail
Aluminum joinery flush with bottom of extrusion
Expandable foam insulation to external mount cavity, refer to Engineers detail
2420mm ceiling to Bathroom only
to top of door/window
Water Tanks
20°
3 888
to top of solar panels
2 850


Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the insulation (Attached to the Specification).
M8 Blind Tapped
WALL PLUG
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental Sustainable House
Address :
Project Information
Roof: 20° Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Foundation/Details
Version 05
Sales: XX
QS: XX
Sheet: 5
Scale: 1:50
Drawn: JM
Date: 26/11/2014
Job Number: 139480
Concept Plans
DETAIL "A"
CONCRETE SLAB
EXTERNAL MOUNT BRACKET @1500 mm CRS TYPICAL
EXTERNAL MOUNT BRACKET
All reinforcing is to be Ductility Class E, in accordance with NZS 4671.
SE62 Ductile Mesh to the Slab.
2x DH12
3x DH12
Water tank
DPC
DH12
520
400
420
100
FOUNDATION DETAILS
16.76 sqm concrete
9 200
3 400
FOUNDATION PLAN - TBC

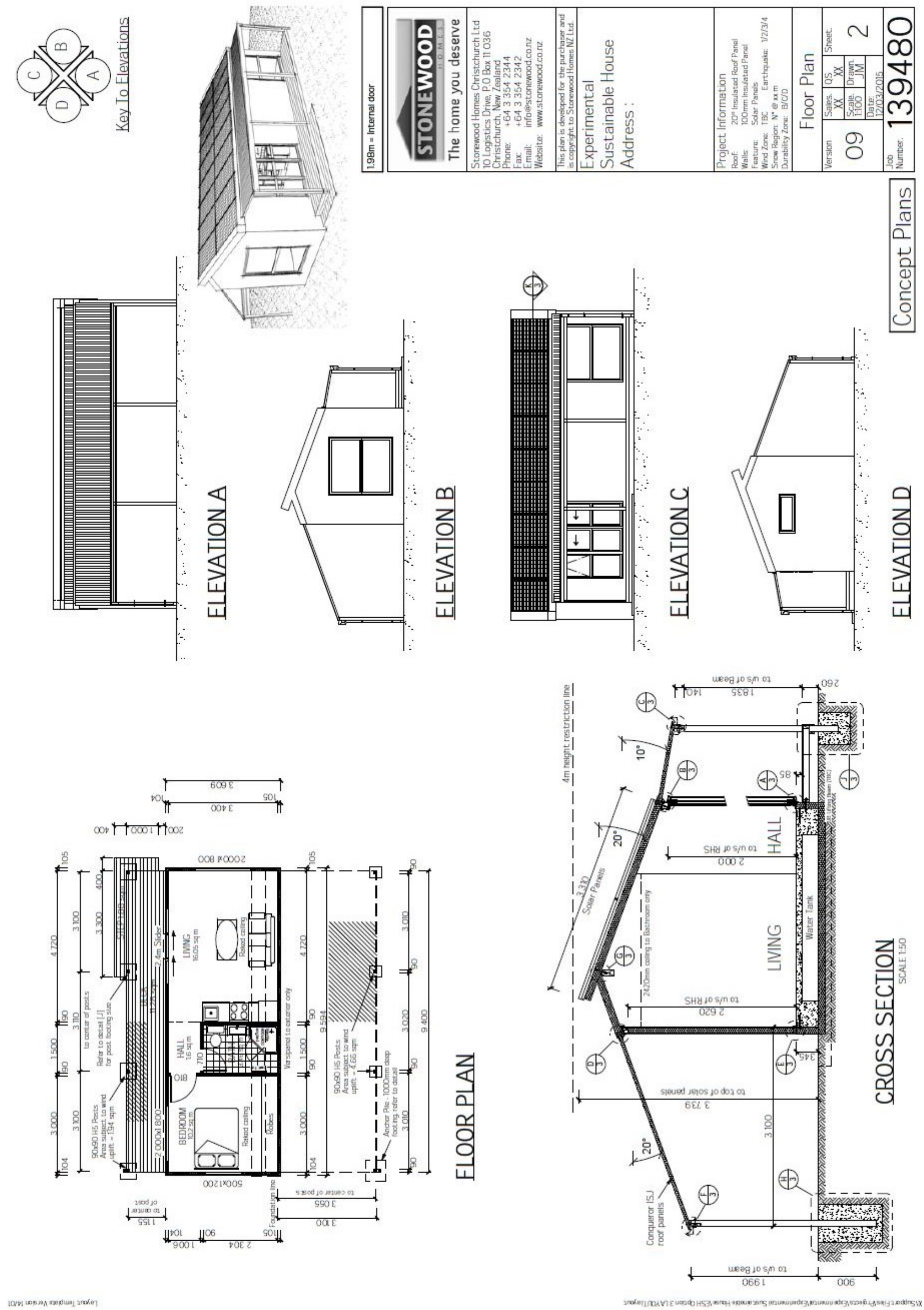

Key To Elevations
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
CROSS SECTION
SCALE 1:50
1.98m = Internal door
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
E-mail: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental Sustainable House
Address :
Project Information
Floor Plan
Version 06
Scale 1:100
Drawn JM
Sheet 4
Date 1/12/2014
Job Number 139480
Concept Plans
LIVING
HALL
BED 1
Water Tanks
4m height restriction line
3 310 Solar Panels
Extrusion connection, refer to Engineers detail
Aluminum joinery flush with bottom of extrusion
Expandable foam insulation to external mount cavity, refer to Engineers detail
2420mm ceiling to Bathroom only
to top of door/window
to top of solar panels
2.4m Slider
1.8m Slider
Raked ceiling
PIR Panel to exterior only

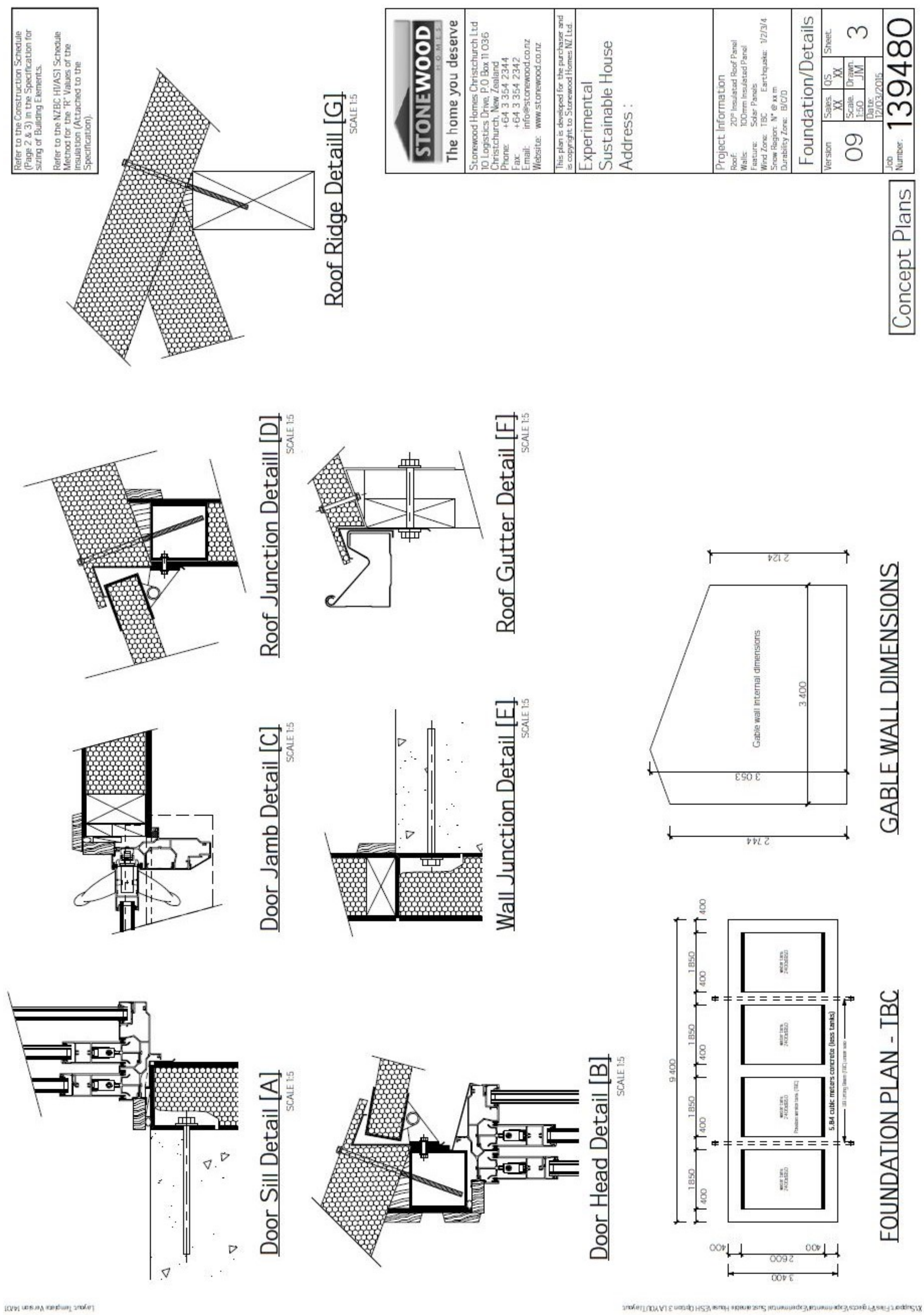

Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the Insulation (Attached to the Specification).
M8 Blind Tapped
WALL PLUG
STONEWOOD
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Project Information
Roof: 20º Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Foundation/Details
Version 06
Sales: XX
QS: XX
Sheet: 5
Scale: 1:50
Drawn: JM
Date: 1/12/2014
Job Number: 139480
Concept Plans
DETAIL "A"
CONCRETE SLAB
EXTERNAL MOUNT BRACKET @1500 mm CRS TYPICAL
EXTERNAL MOUNT BRACKET
All reinforcing is to be Ductility Class E, in accordance with NZS 4671.
SE62 Ductile Mesh to the Slab.
2x DH12
3x DH12
Water tank
DPC
505
400
DH12
420
100
FOUNDATION DETAILS
9 200
3 400
15 sqm concrete
FOUNDATION PLAN - TBC
Layout Template Version 1401


Key To Elevations
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
CROSS SECTION
SCALE 1:50
STONEWOOD HOMES
The home you deserve
Experimental Sustainable House
Address :
Floor Plan
Concept Plans
139480
4m height restriction line
LIVING
HALL
Water Tanks
CARPORT
DECK
BED 1

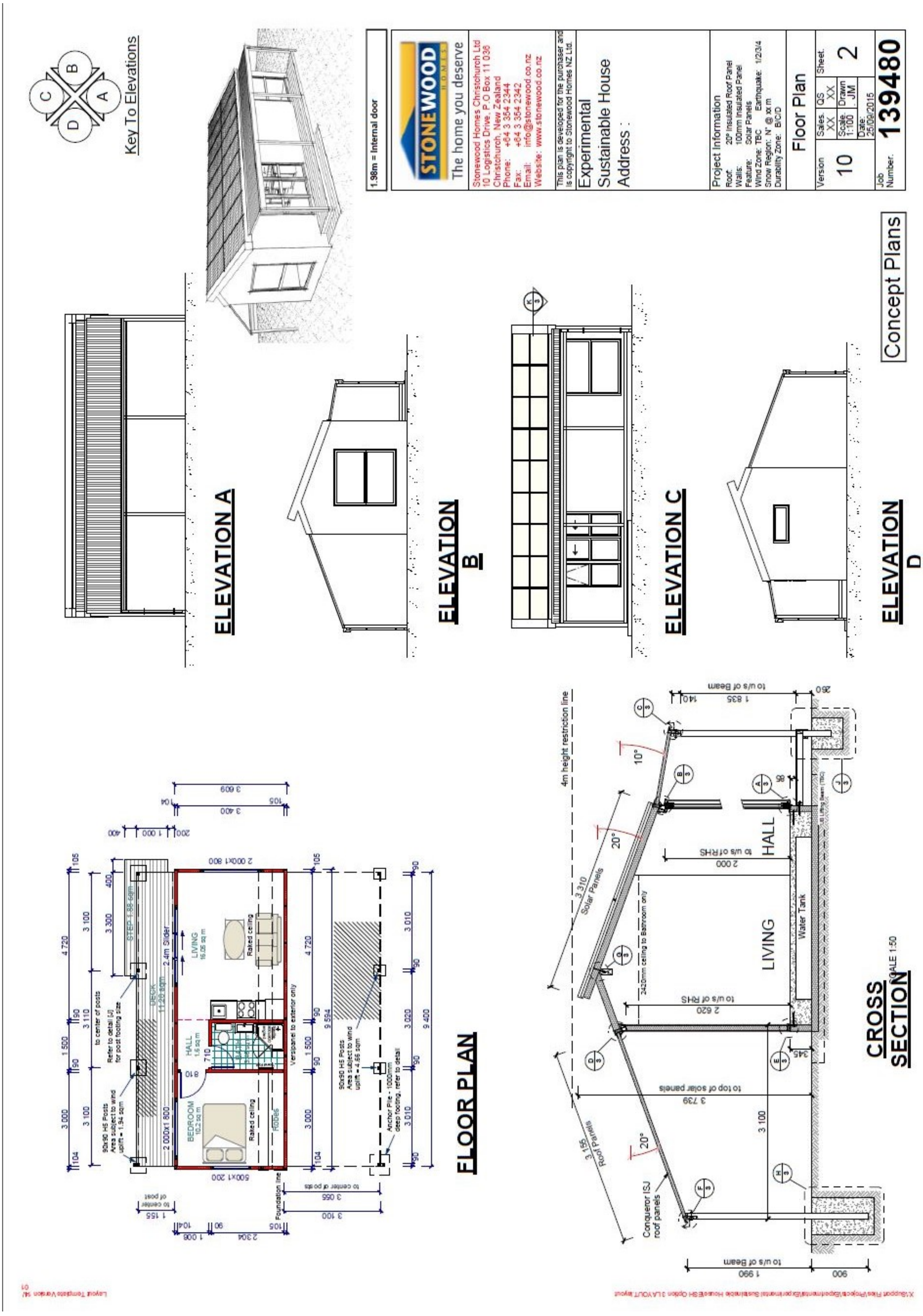

Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the Insulation (Attached to the Specification).
M8 Blind Tapped
WALL PLUG
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental Sustainable House
Address :
Project Information
Roof: 20" Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Durability Zone: B/C/D
Foundation/Details
Version 08
Sales XX
QS XX
Scale 1:40
Drawn JM
Sheet 3
Date 16/12/2014
Job Number: 139480
Concept Plans
DETAIL "A"
CONCRETE SLAB
EXTERNAL MOUNT BRACKET @1500 mm CRS TYPICAL
EXTERNAL MOUNT BRACKET
Gable wall internal dimensions
3 400
3 059
2100
2780
GABLE WALL DIMENSIONS
All reinforcing is to be Ductility Class E, in accordance with NZS 4671.
SE62 Ductile Mesh to the Slab.
2x DH12
3x DH12
DH12
Water tank
DPC
400
505
420
100
FOUNDATION DETAILS
9200
15 sqm concrete
FOUNDATION PLAN - TBC

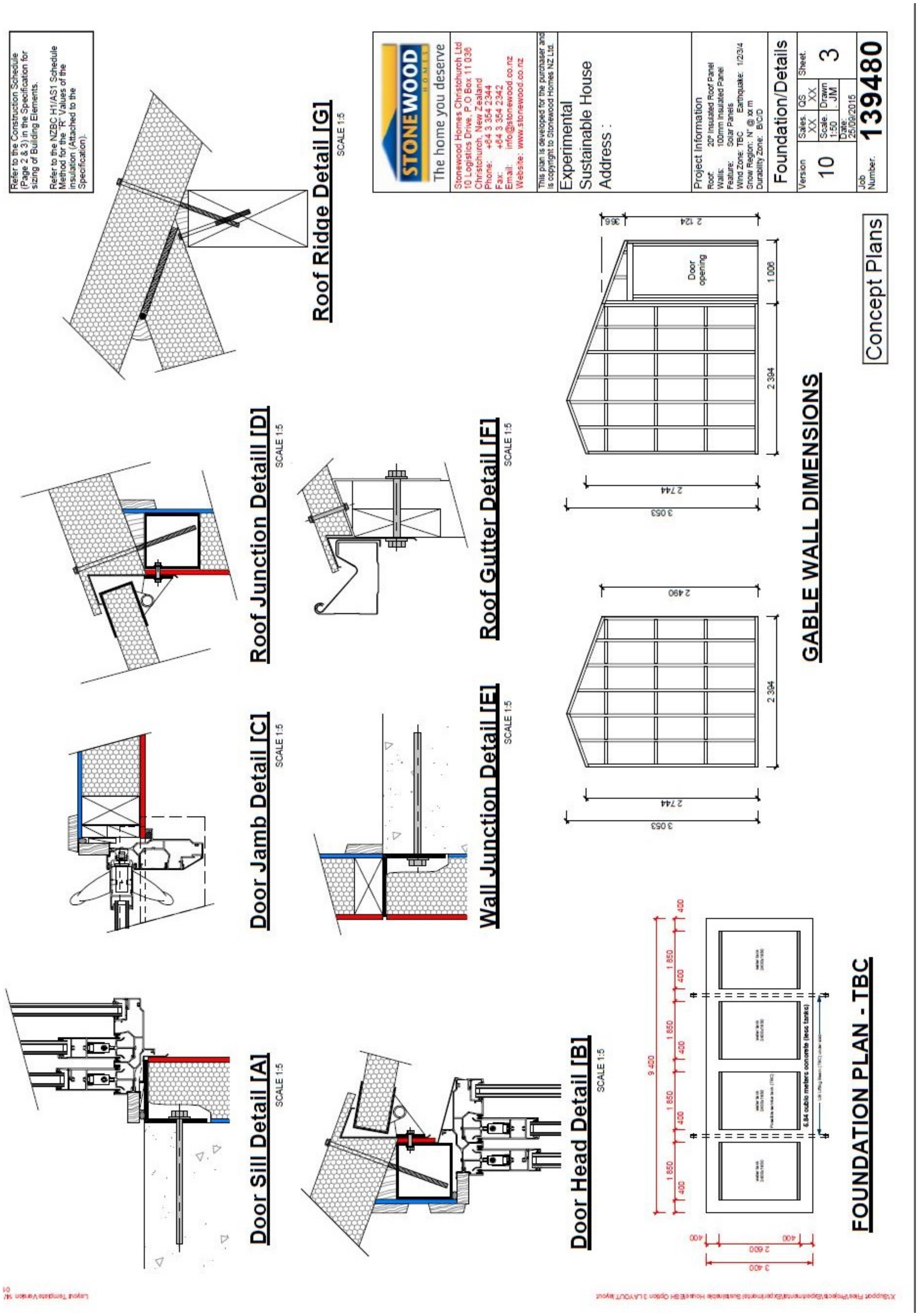

STONEWOOD
HOMES
The home you deserve
Experimental Sustainable Home

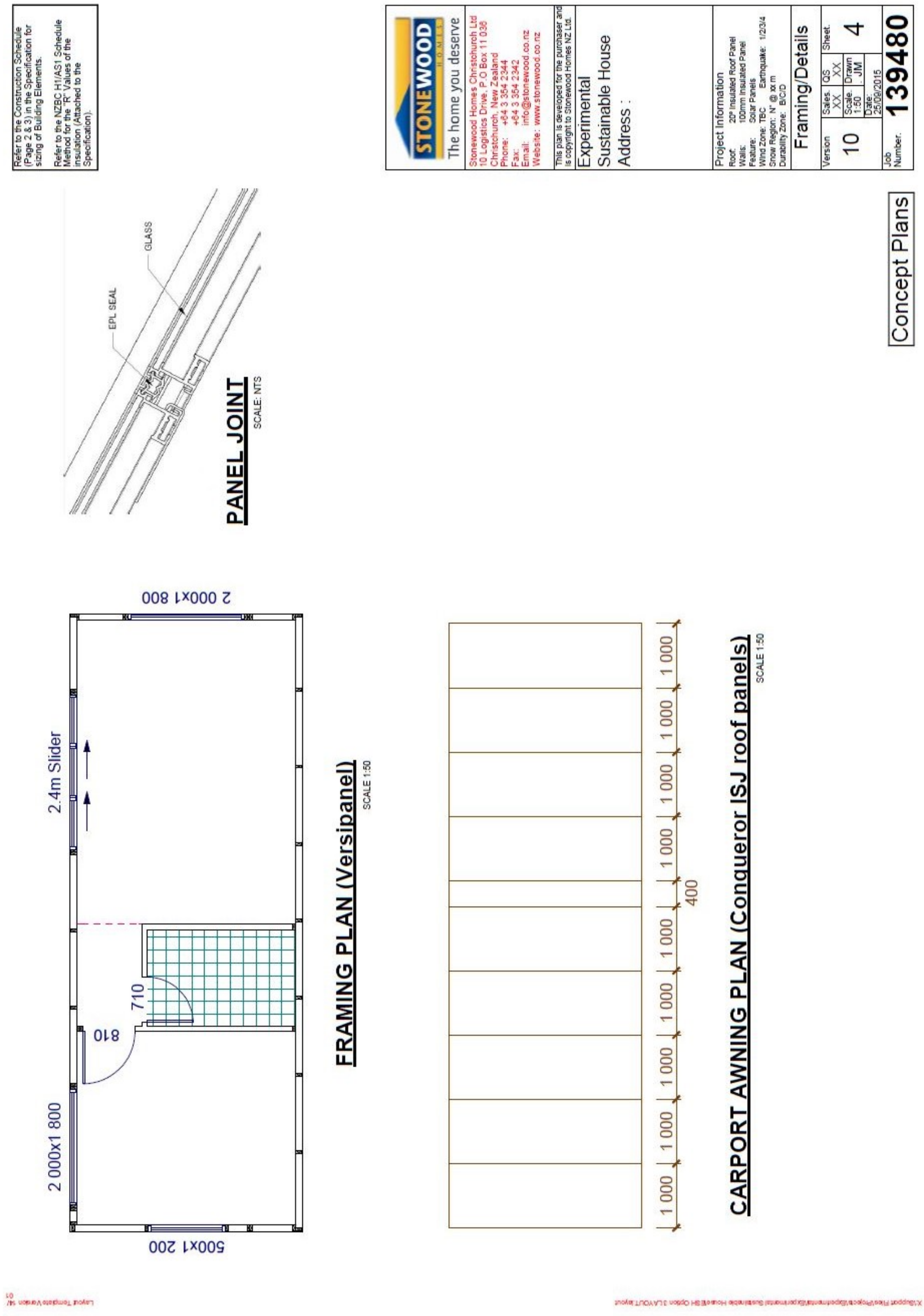

Key To Elevations
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
FLOOR PLAN
CROSS SECTION
SCALE 1:50
LIVING
HALL
BEDROOM
Water Tank
4m height restriction line
Solar Panels
Conqueror ISJ roof panels
1.98m = Internal door
STONEWOOD
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Project Information
Roof: 20º Insulated Roof Panel
Walls: 100mm Insulated Panel
Features: Solar Panels
Floor Plan
Version 09
Scale 1:100
Sheet 2
Date 12/03/2015
Job Number 139480
Concept Plans

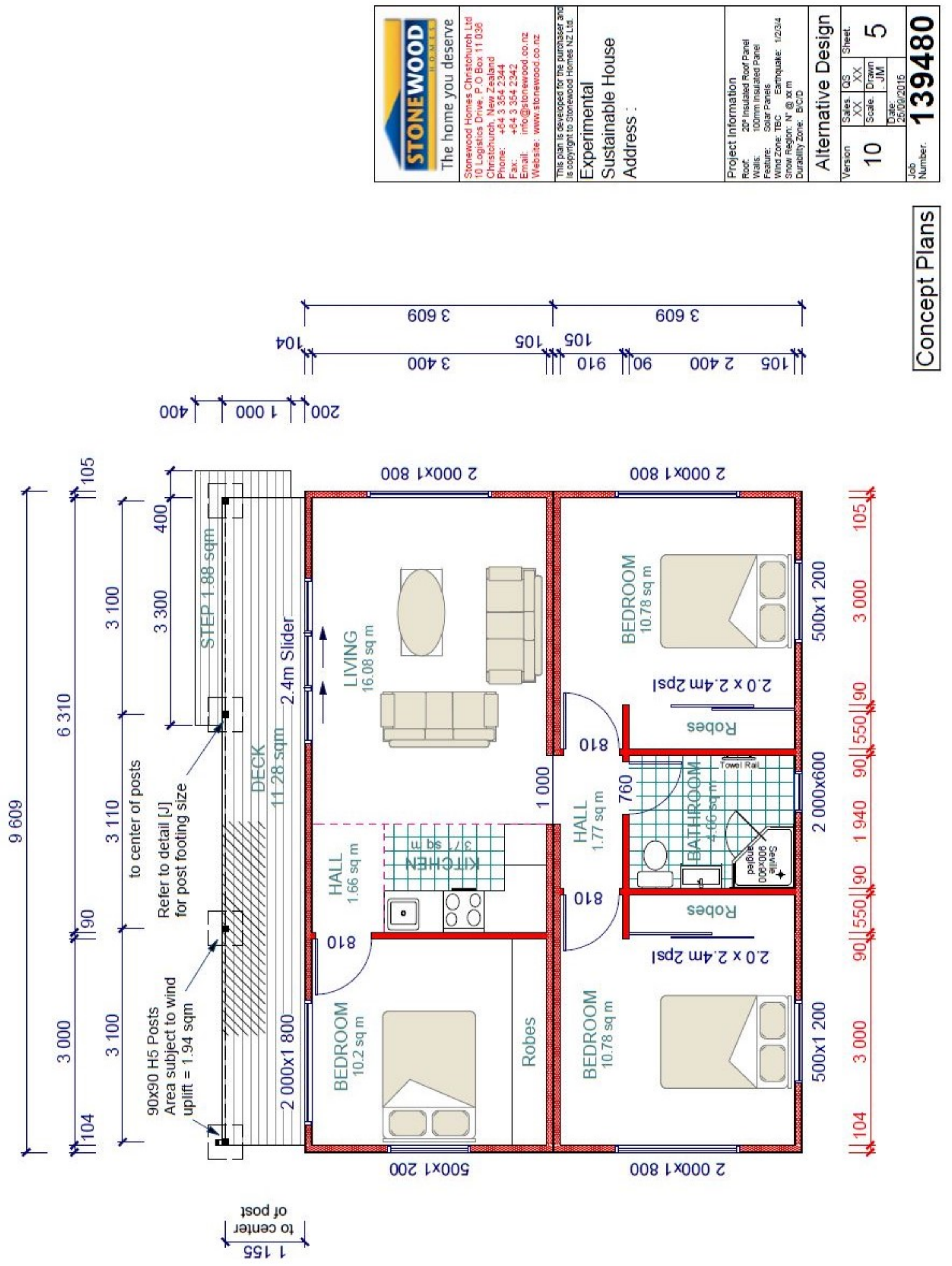

Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the insulation (Attached to the Specification).
Roof Ridge Detail [G]
SCALE 1:5
Roof Junction Detaill [D]
SCALE 1:5
Roof Gutter Detail [F]
SCALE 1:5
Door Jamb Detail [C]
SCALE 1:5
Wall Junction Detail [E]
SCALE 1:5
Door Sill Detail [A]
SCALE 1:5
Door Head Detail [B]
SCALE 1:5
Gable wall internal dimensions
2 124
3 400
3 053
2 744
GABLE WALL DIMENSIONS
9 400
1 850
400
5.84 cubic meters concrete (less tanks)
2 600
3 400
FOUNDATION PLAN - TBC
STONEWOOD
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Project Information
Roof: 20° Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Foundation/Details
Version 09
Sales. XX
QS XX
Scale. 1:50
Drawn. JM
Date: 12/03/2015
Sheet. 3
Job Number. 139480
Concept Plans


STONEWOOD HOMES
The home you deserve
Experimental Sustainable Home


Key To Elevations
ELEVATION A
ELEVATION B
ELEVATION C
ELEVATION D
1.98m = Internal door
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental Sustainable House
Address :
Project Information
Floor Plan
Version 10
Scale 1:100
Drawn JM
Sheet 2
Date: 25/09/2015
Job Number. 139480
Concept Plans
FLOOR PLAN
BEDROOM
HALL
LIVING
DECK
CROSS SECTION
SCALE 1:50
LIVING
HALL
Water Tank
3 310 Solar Panels
3 155 Roof Panels
4m height restriction line


Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the insulation (Attached to the Specification).
Roof Ridge Detail [G]
SCALE 1:5
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Project Information
Roof: 20º Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Foundation/Details
Version 10
Sales. XX
QS XX
Sheet. 3
Scale. 1:50
Drawn JM
Date: 25/09/2015
Job Number. 139480
Concept Plans
Roof Junction Detail [D]
SCALE 1:5
Roof Gutter Detail [F]
SCALE 1:5
Door Jamb Detail [C]
SCALE 1:5
Wall Junction Detail [E]
SCALE 1:5
Door opening
366
2 124
1 008
2 394
2 744
3 053
2 490
GABLE WALL DIMENSIONS
Door Sill Detail [A]
SCALE 1:5
Door Head Detail [B]
SCALE 1:5
9 400
1 850
400
6.84 cubic meters concrete (less tanks)
400
2 600
3 400
FOUNDATION PLAN - TBC


Refer to the Construction Schedule (Page 2 & 3) in the Specification for sizing of Building Elements.
Refer to the NZBC H1/AS1 Schedule Method for the "R" Values of the insulation (Attached to the Specification).
EPL SEAL
GLASS
PANEL JOINT
SCALE: NTS
STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Project Information
Roof: 20º Insulated Roof Panel
Walls: 100mm Insulated Panel
Feature: Solar Panels
Wind Zone: TBC Earthquake: 1/2/3/4
Snow Region: N° @ xx m
Durability Zone: B/C/D
Framing/Details
Version 10
Sales: XX
QS: XX
Sheet: 4
Scale: 1:50
Drawn: JM
Date: 25/09/2015
Job Number: 139480
Concept Plans
2.4m Slider
2 000x1 800
2 000x1 800
500x1 200
810
710
FRAMING PLAN (Versipanel)
SCALE 1:50
1 000
1 000
1 000
1 000
1 000
1 000
1 000
1 000
1 000
400
CARPORT AWNING PLAN (Conqueror ISJ roof panels)
SCALE 1:50


STONEWOOD HOMES
The home you deserve
Stonewood Homes Christchurch Ltd
10 Logistics Drive, P.O Box 11 036
Christchurch, New Zealand
Phone: +64 3 354 2344
Fax: +64 3 354 2342
Email: info@stonewood.co.nz
Website: www.stonewood.co.nz
This plan is developed for the purchaser and is copyright to Stonewood Homes NZ Ltd.
Experimental
Sustainable House
Address :
Project Information
Alternative Design
Version 10
Sheet 5
Drawn JM
Date: 25/09/2015
Job Number. 139480
Concept Plans
LIVING
16.08 sq m
BEDROOM
10.78 sq m
BEDROOM
10.78 sq m
BEDROOM
10.2 sq m
HALL
1.66 sq m
HALL
1.77 sq m
KITCHEN
BATHROOM
Robes
Towel Rail
DECK
11.28 sqm
STEP 1.88 sqm
2.4m Slider
2.0 x 2.4m 2psl
2 000x1 800
500x1 200
2 000x600
90x90 H5 Posts
Area subject to wind
uplift = 1.94 sqm
Refer to detail [J]
for post footing size
to center of posts
to center of post
1 155
9 609
6 310
3 000
3 100
3 110
3 300
3 609
3 400
2 400
810
760
1 000

Appendix D

Building Cost Sheet

	QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
Experimental Sustainable House	**Total Cost Estimate**		**$ 96,496.70**	**PLUS GST**	**$ 110,971.20**						

Notes
Excluding Engineering and Consenting Costs
Excluding Utility Connection Cost
Excluding Transport to site

		QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
#############	Foundation: Formed in factory											
1.10	Pellets 1.2m x 3.4m min	8	$ 75.00	each	600			600				
								0				
1.20	SHS 100x100 for lifting (3 no)	15	$ 100.00	lin m allow	$ -		*quoted below United Steel Quote*	0				
								0				
1.30	100mm PIR Rigid Insulation Panel 3.4m x 9.4m	32	$ 73.05	m2	$ 2,337.60			2337.6				
	Forming base of formwork and Cast insitu into Foundation							0				
	Transported with roof panels ex - Conqueror							0				
								0				
1.40	Formwork Ply - Construction Ply H3.2 DD 2400x1200							0				
1.4.1	Perimeter Foundation 12.93m2/ 2.88m2 per sheet	5	$ 30.95	sheets	$ 154.75		Reusable					154.75
1.4.2	Perimeter Water Tanks 14.95m2/ 2.88 m2	6	$ 30.95	sheets	$ -		Not Required					
						$ 154.75		0				
1.50	Timber 90x45 H3.2 for re-use for Formwork Shutters (9045RLF8H3C)							0				
1.5.1	Shutter sides of foundation	60	$ 4.11	lin m	$ 246.60		Reusable					$ 246.60
1.5.1	Shutter ends of foundation	24	$ 4.11	lin m	$ 98.64		Reusable					$ 98.64
1.5.1	Shutter ends for water tanks	52.8	$ 4.11	lin m	$ -		Not Required					
1.5.1	Shutter sides for water tanks	71.92	$ 4.11	lin m	$ -		Not Required					
						$ 345.24		0				
	Timber 90x45 H3 for bracing and blocking Formwork Shutters							0				
1.5.2	Perimeter top and bottom external formwork	79.8	$ 4.11	lin m	$ 327.98		Reusable					$ 327.98
1.5.2	Diagonal Bracing external formwork	31	$ 4.11	lin m	$ 127.41		Reusable					$ 127.41
1.5.2	Blocking Formwork Water tanks	180	$ 4.11	lin m	$ -		Not Required					
						$ 455.39		0				
1.60	M12 Bolts Screw Thread + Washer - bottom plate shutter formwork into PIR							0				
	Perimeter of external shutters	100	$ 1.50	allowance	$ 150.00		Reusable					$ 150.00
	Water Tank Shutters	80	$ 1.50	allowance	$ -		Not Required					
								0				
1.70	Rattle Gun Hire	1	$ 50.00	day	$ 50.00			50				
								0				
1.80	Reinforcing Steel							0				
1.8.1	Perimeter Beam (5DH12 detail)	26	$ 7.78	lengths	$ 202.28			202.28				
1.8.1	Internal Beams(5DH12 detail)	10	$ 7.78	lengths	$ 77.80			77.8				
								0				
1.8.2	Stirrups 300mm x 425mm- *Yes Sean*	44	$ 3.50	Allowance	$ 154.00			154				
								0				
1.8.3	Starters not required. *Sean*	0	$ 1.86	each	$ -			0				
								0				
1.8.4	Reinforcing Mesh SE62 3.4m x 9.4m (Sheets 5.0 x 2.27)	4	$ 67.74	sheets	$ 270.96			270.96				
								0				
1.8.5	Bar chairs 20-40 (Bags of 100)	200	$ 0.15	each	$ 30.00			30				
								0				
1.8.6	Wire Ties Bundles (1kg)	5	$ 3.00	bundles	$ 15.00			15				
								0				
1.90	Concrete 20 Mpa / 19mm							0				

	QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
1.9.1 Foundation Concrete 20Mpa Beams and Floor Slab Topping	9	$ 171.50	m3	$ 1,543.50			1543.5				
1.9.2 Concrete Pump min charge	1	$ 450.00	total	$ 450.00			450				
1.9.3 Concrete Placer Floor Screed (3.4m x 9.4m)	32	$ 6.00	m2	$ 192.00			192				
1.9.3 Concrete Placer Additional cost as min charge TBC	1	$ 110.00	allowance	$ 110.00			110				
							0				
1.10. DPC Foundation Detail							0				
1.10.1 Allow Polythene Black 250MU 4 X 25M Roll	1	$ 59.70	roll	$ 59.70			59.7				
1.10.2 DPC between bottom plate and slab							0				
Malthoid DPC 200MM X 20M Dampcourse per Roll	2	$ 15.14	roll	$ 30.28			30.28				
							0				
1.11 Lumberlok Bottom Plate Fix Anchor	44	$ 0.92	each	$ 40.48			40.48				
							0				
1.12 Anchor Fixings bottom plate to slab by Engineer	1	$ 300.00	allowance	$ 300.00			300				
							0				
1.13 Inslab Pipework - *allowance under plumbing*	1		note				0				
							0				
1.14 Earth Rod	1	$ 4.90	each	$ 4.90			4.9				
							0				
1.15 Freight Costs Foundation							0				
Pellets and timber ex-Carters	1	$ 110.00	Total	$ 110.00			110				
Reinforcing Steel and SHS United Steel	1	$ 100.00	Total	$ 100.00			100				
							0				
1.16 Water Tanks to be place in Foundation							0				
1.16.1 Thin Tanks NZ	4	$ 1,261.00	each	$ 5,044.00			5044				
1.16.2 Freight hiab hire	2	$ 150.00	hours	$ 300.00			300				
							0				
1.17 Custom Plumbing to allow fill from top / drain from bottom - to exterior of foundation							0				
Materials	4	$ 100.00	allowance	$ 400.00			400				
Labour place, fill, pressure test	4	$ 100.00	allowance	$ 400.00			400				
							0				
1.18 Builders Labour Foundation							0				
Formwork - Build re-useable shutters (Prototype PW 30hrs)	15	$ 50.00	hours	$ 750.00		Reusable - 15Hours less with no water tank formwork					$ 750.00
Reinforcing (2 men / 2 days @ 7.5hrs)	15	$ 50.00	hours	$ 750.00			750				
Place Water Tanks	2	$ 50.00	hours	$ 100.00			100				
Foundation Beams supervise pour/ vibrate	2	$ 50.00	hours	$ 100.00			100				
					$ 1,700.00		0				
							0				
############# **Framing RAD 90 x 45 SGF7. H3.2 As external no cavity**							0				
							0				
2.10 Timber for exterior Versipanel Exterior Walls.	148	$ 4.11	lin m	$ 608.28			608.28				
2.20 Timber for interior framing	84.4	$ 4.11	lin m	$ 346.88			346.884				
							0				
							0				
3.00 Exterior Versipanel 6mm Fibre Cement - Exterior Cladding							0				
							0				
3.10 6mm Versipanel 103mm thickness 1200mm width Panels							0				
As per Sean's number of 22 panels - Patrick 2 sheets less but being freighted from Australia							0				
							0				
7 x 2400	7	$ 183.30	each	$ 1,283.10			1283.1				
3 x 2700	3	$ 206.54	each	$ 619.62			619.62				
9 x 3000	9	$ 229.85	each	$ 2,068.65			2068.65				
3 x 3600	3	$ 292.85	each	$ 878.55			878.55				
22 panels total					*$ 4,849.92*		0				
							0				

No.	Item	Detail	QTY	$	Unit	Subtotal ($)	Total	Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
3.20	Veriscad Hot Knife Cutter		1	$ 365.93	each	$ 365.93		reuseable					365.93
									0				
3.30	Freight from Australia Port to Port		1	$ 2,326.86	quote	$ 2,326.86			2326.86				
									0				
3.40	Freight Port to site								0				
3.4.1	Hiab Hire - load, deliver, unload		3	$ 150.00	hours	$ 450.00			450				
									0				
3.50	Scaffold								0				
3.5.1	Mobile Scaffold		1	$ 300.00	week	$ 300.00			300				
									0				
3.60	Miscellaneous								0				
	Meter box		*not required off grid*						0				
									0				
3.70	Builders labour Framing and Walls								0				
	To assemble External Walls	2 men 1 days prototype PW	16	$ 50.00	hours	$ 800.00		60hours proto - 20hours recurring	$ 266.67				$ 533.33
	To assemble Internal Walls	2 men 1 day PW review 1 day	16	$ 50.00	hours	$ 800.00		*20hours proto - 5hours recurring/ prenai*	250				750
							$ *1,600.00*	**Not priced as prenail - required**	0				
									0				
4.00	Windows								0				
									0				
	500h x 1200w Awning for ventilation. WA512		1	$ 288.43	each	$ 288.43			288.43				
	2000h x 2400w slider. (Used DSA 2124-3 value)		1	$ 1,836.47	each	$ 1,836.47			1836.47				
	2000h x 1800w Fixed (Used WA2118 value)		2	$ 981.14	each	$ 1,962.28			1962.28				
	Allowance for non standard windows		1	$ 500.00	allowance	$ 500.00			500				
	Freight		1	$ 125.00	total	$ 125.00			125				
							$ *4,712.18*		0				
									0				
5.00	Interior Doors (1980mm)								0				
	810 - Everest (vertical V groove) RVG1 MDF		1	$ 131.00	each	$ 131.00			131				
	710 - Everest (vertical V groove) RVG1 MDF		1	$ 131.00	each	$ 131.00			131				
	Freight		2	$ 10.00	each	$ 20.00			20				
									0				
	Door Hardware		2	$ 30.00	set	$ 60.00			60				
									0				
	Builders labour to install		1	$ 50.00	hour	$ 50.00			50				
							$ *392.00*		0				
									0				
6.00	**Roof Beam 190 x 90 RAD H3 MSG8 - HYNE I BEAM H3.1 200 X 90 PER MTR**								0				
									0				
6.10	Length 4.74m Order 5.4m		5.4	$ 21.23	lin m	$ 114.64			114.642				
6.10	Length 4.87m Order 5.4m		5.4	$ 21.23	lin m	$ 114.64			114.642				
									0				
6.20	Builders Labour		1	$ 50.00	hours	$ 50.00		2 hours proto - 1 hour recurring	50				50
									0				
									0				
7.00	**Verispanel Wall Panel to Slab Steel Angle**								0				
									0				
7.10	Steel 100 x 6 equal angle		30	$ 50.00	lin m allow	$ -	*quoted below United Steel Quote*		0				
7.20	Dynabolts angle to slab RAMSET DYNABOLT HEX GALV M10 100MM I		45	$ 2.37	each	$ 106.65			106.65				
									0				
7.30	Builders Labour. 1 man 6 hours		2	$ 50.00	hours	$ 100.00		6Hours Proto - 2 Hours recurring	100				200
									0				
									0				
8.00	**Fascia /Gutter - Squareline - Metalcraft Zincalume**								0				

	QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
							0				
Metal Fascia - Squareline Gutter Fascia colour - To be advised							0				
Supply and install	19.2	$ 33.20	lin m	$ 637.44			637.44				
							0				
							0				
9.00 **Barge**							0				
Barge cap Flashings (20x80x180) supply and install	8.8	$ 35.00	allow lin m	$ 308.00			308				
Rivets							0				
Sealant							0				
							0				
							0				
10.00 **Downpipes**							0				
Supply and install							0				
Coloursteel Rectangular 75x55mm (SI Only) - Downpipe	2	$ 123.86	each	$ 247.72			247.72				
Downpipe Droppers	2	$ 2.50	each	$ 5.00			5				
							0				
							0				
11.00 **Roof - Conqueror Panels - Steel Foam Steel - ISJ Panels**							0				
							0				
ISJ Panels 100mm - House Roof - 9594mm x 3310mm	32	$ 90.00	m2	$ 2,880.00			2880				
ISJ Panels 100mm - House Roof - 9594mm x 1100mm	10.5	$ 90.00	m2	$ 945.00			945				
ISJ Panels 50mm - Porch Roof - 9400mm x 1250mm	12	$ 65.00	m2	$ 780.00			780				
ISJ Panels 50mm - Carport Roof - 9400mm x 3200mm	30	$ 65.00	m2	$ 1,950.00					$ 1,950.00		
					$ 6,555.00		0				
Freight Hiab ex CHCH to site	2	$ 150.00	hours	$ 300.00			300				
							0				
Builders Labour House Roof Panels Lift and fix (2 man .5day)	10	$ 50.00	hours	$ 500.00			$ 500.00				
Builders Labour Porch and Carport assemble ground lift place	10	$ 50.00	hours	$ 500.00		30Hours Prototype - 10Hours recurring	$ 250.00		$ 250.00		1000
					$ 1,000.00		0				
							0				
12.00 **Veranda/ Carport Posts**							0				
90 X 90 RAD GLULAM POST H3 PER METRE							0				
4 x Veranda 90 x 90 H5 MG (2.4m) - 5.4m lenghts	10.8	$ 19.23	lin m	$ 207.68			207.684				
4 x Carport 90 x90 H5 MG (2.9m) - 6.0m lenghts	12	$ 19.23	lin m	$ 230.76					$ 230.76		
Labour dig holes and place posts	4	$ 50.00	hours	$ 200.00			$ 100.00		$ 100.00		
					$ 638.44		0				
							0				
13.00 **Beams For Veranda**							0				
*140 X 45 RADIATA MSG10 STRESS GRADED H3.1 KD *EMS**							0				
Beams for posts 140 x 45 H3.1 SG8 MG	18.8	$ 5.41	lin m	$ 101.71			$ 50.85		$ 50.85		
Blocking Between Posts 140 x 45 H3.1 SG8 MG	18.8	$ 5.41	lin m	$ 101.71			$ 50.85		$ 50.85		
Labour	4	$ 50.00	hour	$ 200.00			$ 100.00		$ 100.00		
					$ 403.42		0				
							0				
14.00 **M10 Bolts for Vernada Beam to Post**							0				
M10 X 150 COACH BOLT/NUT GALV EACH							0				
8 x M10 150mm Bolts / Nut Galv	8	$ 0.79	each	$ 6.32			$ 3.16		$ 3.16		
16 no. 50 x 50 x 3	16	$ 0.45	each	$ 7.20			$ 3.60		$ 3.60		
Labour	1	$ 50.00	hour	$ 50.00			$ 25.00		$ 25.00		
					$ 63.52		0				
							0				
15.00 **Steel 90 x90 x 3 Custom Angle Timber Beam/Roof Junction**							0				
							0				
90 x 90 x 3 custom angle steel - fabricate, deliver - Porch Beam	9.4	$ 100.00	lin m allow	$ -	*needs quote*	Incl. Quoted Bromley dated 30.4.15			$ -		
90 x 90 x 3 custom angle steel - fabricate, deliver - Carport Beam	9.4	$ 100.00	lin m allow	$ -	*needs quote*	*Quote bottom of costing*	0				

	QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
Labour install Blind Rivets Custom Angle to Roof Porch/Carport	4	$ 50.00	hours	$ 200.00			$ 100.00		$ 100.00		
					$ 200.00		0				
							0				
16.00 **Veranda Roof/ House Connection**							0				
							0				
75 x 56 x 3 "C" Channel	9.4	$ 60.00	lin m allow	$ -	*needs quote*	Incl. Quoted Bromley dated 30.4.15			$ -		
3 no. Special Brackets	3	$ 250.00	allowance	$ -	*needs quote*	*Quote bottom of costing*			$ -		
3 x M10 Blind Bolts	3	$ 10.00	allowance	$ 30.00					$ 30.00		
Labour install onsite	3	$ 50.00	hours	$ 150.00					$ 150.00		
					$ 180.00						
17.00 **Porch Roof / House Connection**							0				
							0				
75 x 56 x 3 "C" Channel	9.4	$ 60.00	lin m allow	$ -	*needs quote*	Incl. Quoted Bromley dated 30.4.15	0				
3 no. Special Brackets	3	$ 250.00	allowance	$ -	*needs quote*	*Quote bottom of costing*	0				
3 x M10 Blind Bolts	3	$ 10.00	allowance	$ 30.00			30				
Labour install onsite	3	$ 50.00	hours	$ 150.00			150				
					$ 30.00		0				
							0				
18.00 **House Wall / Roof Junction**							0				
							0				
18.10 89 x 4 SHS Steel	20	$ 90.00	lin m allow	$ -	*quoted below United Steel Quote*		0				
Labour to place	1	$ 50.00	hour	$ 50.00			50				
18.20 M8 Blind Bolt (Allow 3 per panel) 210mm	30	$ 3.50	each allow	$ 105.00			105				
18.20 M8 Blind Bolt (Allow 3 per panel) 170mm	30	$ 3.00	each allow	$ 90.00			90				
							0				
18.30 Labour under fixings allowed for under Roof Panels	1		note				0				
							0				
							0				
19.00 **Roof to Beam Connection**							0				
14g self drilling hex head with seal 3 per panel							0				
30 no. 210mm	30	$ 3.50	each allow	$ 105.00			105				
30 no. 60mm	30	$ 2.50	each allow	$ 75.00			75				
							0				
							0				
20.00 **Post Concrete**							0				
							0				
Allow 9 posts @ 500 x 500 x 500	1.25	$ 171.50	m3	$ 214.38	review		$ 107.19		$ 107.19		
Allow 1 Anchor Pile 1000x500x500	0.25	$ 171.50	m3	$ 42.88			$ 21.44		$ 21.44		
							0				
							0				
21.00 **Deck Area**							0				
Radiata Grip Tread Deck 11.28m2 + Steps Area 1.88m2	13.16	$ 300.00	m2	$ 3,948.00						$ 3,948.00	
(Allowance for labour and materials)							0				
							0				
							0				
22.00 **NailS for Wall Panels to Timber**							0				
							0				
Pack of 3000 nails	1	$ 180.00	each allow	$ 180.00			180				
Bottom/ top plate 2.8x30 Flathead @ 80 c/c 650 no.							0				
Studs / trimmers 2.8x30 Flathead @ 80 c/c 550 no.							0				
							0				
							0				
23.00 **Plumbing**							0				
							0				

	QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
23.10 **Plumbing Labour**							0				
Labour Plumbing - slab prepipe	1	$ 150.00	allowance	$ 150.00			150				
Labour Plumbing - inwall prepipe 1 bathroom House	1	$ 250.00	allowance	$ 250.00			250				
Labour sink	1	$ 110.00	each	$ 110.00			110				
Labour Shower & Waste	1	$ 110.00	each	$ 110.00			110				
Labour Vanity Basin & Waste	1	$ 110.00	each	$ 110.00			110				
Labour Toilet	1	$ 70.00	each	$ 70.00			70				
Terminal Vents	1	$ 70.00	each	$ 70.00			70				
Plumbing Material Sundries	1	$ 150.00	Total	$ 150.00			150				
					$ 1,020.00		0				
23.20 **Plumbing Material**							0				
Basic Slab Pipework	1	$ 300.00	allowance	$ 300.00			300				
COP5 - Water Entry - finishing	1	$ 39.25	each	$ 39.25			39.25				
FIN2 - Shower - inwall	1	$ 64.33	each	$ 64.33			64.33				
Basins - inwall	1	$ 52.22	each	$ 52.22			52.22				
Basins - finishing	1	$ 52.50	each	$ 52.50			52.5				
Toilets - inwall	1	$ 35.38	each	$ 35.38			35.38				
Toilets - finishing	1	$ 53.47	each	$ 53.47			53.47				
HWC - inwall	1	$ -	each	$ -			0				
HWC - finishingHWC - finishing	1	$ -	each	$ -			0				
DRN4 - Wall Kitchen - inwall	1	$ 42.66	each	$ 42.66			42.66				
DRN6 - Wall Kitchen - finishing	1	$ 102.68	each	$ 102.68			102.68				
Terminal Vent - finishing - Metal roof	1	$ 110.04	each	$ 110.04			110.04				
Plumber Small Trips	3	$150		$ 450.00							$ 450.00
					$ 852.53		0				
							0				
24.00 **Gas**							0				
Gas HWC: Bosch 26E gas water heater	1	$ 1,118.54	each	$ 1,118.54		Sean to review	1118.54				
Recess Box & Premium Main Controller	1	$ 345.98	each	$ 345.98			345.98				
Twin cylinder gas station/ regulator Prepipe	1	$ 271.75	each	$ 271.75			271.75				
Twin cylinder gas station and regulator- fit off	1	$ 271.75	each	$ 271.75			271.75				
Prepipe gas hob	1	$ 242.50	each	$ 242.50			242.5				
Fit Off gas hob	1	$ 242.50	each	$ 242.50			242.5				
Gas Certificate	1	$ 70.00	each	$ 70.00			70				
					$ 2,563.02		0				
							0				
23.00 **Solar Panels**							0				
							0				
23.10 **18 PV Panels SWH pricing**							0				
2kW 8 Panel Photovoltaic Kit	2.25	$ 5,360.00	each	$ 12,060.00							
Photo Voltaic Freight - 8 panel kit	2.25	$ 180.00	each	$ 405.00							
Photo Voltaic Installation	2.25	$ 1,000.00	each	$ 2,250.00							
					$ 14,715.00		0	$ 14,715.00			
23.20 **PV Inverter Quote**							0				
Quote USD $3,711.20 incl Freight. 1 USD = 1.3 NZD	1	$ 4,824.56	Quote	$ 4,824.56				$ 4,824.56			
							0				
23.30 **Batteries**							0				
Quote NZD incl Freight	1	$ 4,540.00	Quote	$ 4,540.00				$ 4,540.00			
23.40 PV Electrical											
Labour	5	50/hr	Allowance	250				250			
							0				
24.00 **Kitchen**							0				
Kitchen Joinery	1	$ 1,750.00	Allowance	$ 1,750.00		Sean to review	1750				

	QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
Kitchen Joinery Freight	1	$ 234.78	Total	$ 234.78			234.78				
Splashback gas hob	1	$ 310.00	Total	$ 310.00			310				
					$ 2,294.78		0				
							0				
25.00 **Flooring**							0				
Polished Concrete - exposed for thermal mass	1	$ 500.00	Allowance	$ 500.00		Sean to review	500				
							0				
							0				
26.00 **Appliances**							0				
PBH615B9TA - Bosch PCH615B9TA 4 burner gas hob	1	$ 441.00	each	$ 441.00		Sean to review	441				
HBA11B150A - Bosch HBA11B150A (SS) oven	1	$ 614.00	each	$ 614.00		Sean to review	614				
TCH90X - Unbranded Canopy 90cm s/steel TCH90X	1	$ 276.00	each	$ 276.00			276				
524626 - Ducting Kit 150mm Rangehood Top Vent (3m) - DCT1259	1	$ 93.00	each	$ 93.00			93				
					$ 1,424.00		0				
27.00 **Bathroom**							0				
677513 - Newtech Montana Qube + 750mm wall-hung vanity,	1	$ 361.04	each	$ 361.04			361.04				
524602 - Eclipse 1000x1000 2/S Angle Tray	1	$ 289.03	each	$ 289.03			289.03				
Eclipse 1000x1000 2/S Angle Door and Return	1	$ 720.29	each	$ 720.29			720.29				
651808 - Caroma Venecia Suite	1	$ 219.57	each	$ 219.57			219.57				
627170 - Paffoni Blu Sink Faucet BLU180 CP High spout	1	$ 107.94	each	$ 107.94			107.94				
627169 - Paffoni Blu Basin Mixer BLU071 CP	1	$ 91.80	each	$ 91.80			91.8				
627168 - Paffoni Blu Shower Mixer BLU010LUG CP	1	$ 97.20	each	$ 97.20			97.2				
622353 - Paffoni Slide Set - Lance 1F ZSAL181CR	1	$ 102.00	each	$ 102.00			102				
953206 - Weiss Clearglo - Fan FH705D (Light/Fan/Heat/Ducting)	1	$ 93.75	each	$ 93.75			93.75				
1000 x 900 x 4mm polished edge	1	$ 116.37	each	$ 116.37			116.37				
DHBA-2386 - Tempo Toilet Roll Holder	1	$ 14.18	each	$ 14.18			14.18				
Shower Installer - Acrylic	1	$ 115.00	each	$ 115.00			115				
					$ 2,328.17		0				
28.00 **Electrical**							0				
Standard House Electrical (Usual $1060)	1	$ 550.00	allowance	$ 550.00		Sean to review	550				
PV inverter above	1		note				0				
Switched Light circuit	4	$ 63.00	each	$ 252.00			252				
Exterior Bulkhead light	1	$ 35.30	each	$ 35.30			35.3				
Down light	3	$ 25.00	each	$ 75.00			75				
Double plugs	4	$ 65.00	each	$ 260.00			260				
RCD circuit	1	$ 115.50	each	$ 115.50			115.5				
Hot Water cylinder/gas connection	1	$ 75.00	each	$ 75.00			75				
Built-In oven connection	1	$ 103.00	each	$ 103.00		Sean to review	103				
Gas hob plug	1	$ 63.00	each	$ 63.00			63				
Fridge Plug	1	$ 63.00	each	$ 63.00			63				
Rangehood plug	1	$ 63.00	each	$ 63.00			63				
Heat Fan Light circuit and install ducted system	1	$ 105.00	each	$ 105.00			105				
					$ 1,759.80		0				
29.00 **Gib Stopping**							0				
							0				
Gib Stop internal versipanel joins	1	$ 400.00	allowance	$ 400.00			400				
							0				
30.00 **Interior Painting**							0				
							0				
Internal walls	53	$ 47.50	m2	$ 2,517.50			2517.5				
							0				
31.00 **Exterior Painting**							0				
							0				
Exterior Walls	62	$ 27.50	m2	$ 1,705.00			1705				

		QTY	$	Unit	Subtotal ($)		Notes	Building Recurring	Offgrid	Carport	Deck	Proto Cost
								0				
32.00	**Flashings**							0				
								0				
	Prefabricated Sheet Metal	1	$ 2,000.00	allowance	$ 2,000.00	needs quote		2000				
	Detail A. 10x40x35x10 Flashing Sill											
	Detail B. 10x50x140x10 Flashing Roof edge to Front SHS											
	Detial B. 35x110x10 Flashing SHS to Joinery											
	Detail E. 50x10x50 Flashing Wall Junction											
	Detail F. 10x50x140x10 Flashing Roof/ Gutter/Beam											
33.00	**United Steel Quote #191887 items above highlighted in this quote**											
	100x100/ 89x89/ 100x100x6	1	$ 1,585.68	Quote	$ 1,585.68			$ 1,585.68				
34.00	**Bromley Steel Quote dated 30.4.15**	1	$ 3,172.00	Quote	$ 3,172.00			$ 1,586.00		$ 1,586.00		
	Items included in this quote highlighted above.							Building	Offgrid	Carport	Deck	Proto
				Total	**$ 96,496.70**	**PLUS GST**	**$ 110,971.20**	**$59,705.64**	**$ 24,079.56**	**$3,172.85**	**$ 3,948.00**	5204.6413

Appendix E

Enasolar Inverter Specification Sheet

DC Input:	1.5kW	2.0kW	3.0kW	3.8kW	4.0kW	5.0kW
Number of Inputs:	1x MPPT input				2x independent MPPT inputs	
Maximum Open Circuit Voltage (Voc):	500V	600V	600V	500V	600V per DC input	
DC Full Power Operating Range:	150-450V	185-500V	215-500V	245-350V	200-500V per DC input	235-500V per DC input
Operating Voltage Range (Vmpp):	120-450V	120-450V	120-500V	120-400V	120-500V per DC input	
DC Optimal Operating Voltage:	300V DC	350V DC	375V DC	275V DC	350V per DC input	
Maximum Input Current (Impp):	11.0A	12.0A	15.0A	16.5A	15.0A per DC input	
Maximum Short Circuit Current (Isc)	12.5A	13.5A	16A	19A	16A	
Maximum Usable Input Power (Pmax):	1640Wp	2200Wp	3200Wp	4000Wp	3000Wp per DC input	3500Wp per DC input
Maximum Allowable Input Power:	2250W	3000W	4500W	5000W	6000W total	7000W total
Reverse Polarity Protection:	Inherent crowbar diodes					
Isolation From AC Mains:	Galvanically isolated high frequency transformer					
Earthing:	Isolated, +ve earth, -ve earth selectable					

AC Output:	1.5kW	2.0kW	3.0kW	3.8kW	4.0kW	5.0kW
Nominal Output Voltage:	230V AC single phase					
Output Voltage Range:	202-259V AC (AU/NZ), 208-262V AC (UK)					
Output Power:	1500W	2000W	3000W	3800W 3680W (UK)	4000W	4990W 4600W (AU4.6)
Max Output Current:	7.5A	10.0A	15.0A	16.0A	18.0A	21.5A 21.0A (AU4.6)
Recommened AC Circuit Breaker Size:	16.0A		20.0A		32.0A	
Line Frequency:	50Hz					
Total Harmonic Distortion:	<5% at full load, rominal output voltage					
Max Efficiency:	>96.0%	>96.0%	>96.4%	>96.0%	>96.8%	>96.8%
Max Euro Efficiency:	>93.8%	>94.3%	>94.5%	>94.5%	>94.8%	>95.4%
Power Factor:	>0.98 (30 -100% load)					

System:	1.5kW	2.0kW	3.0kW	3.8kW	4.0kW	5.0kW
Islanding Protection:	AS4777-2, AS4777-3					
	G83/2				G59/2	
Night-time Consumption:	<1.2W					
Operating Temperature Range:	-30°C to +50°C (full power), 40°C for 3.8kW, +70°C (derated)					
Acoustic Noise:	<33dBa @ 1m					
Max Humidity:	100%					
Max Altitude:	2000m					
Display:	4 line x 16 character (no buttons)					
Data Interface:	Wi-Fi IEEE 802.11 (optional Ethernet RJ45) web server built-in for EnaSolar Online remote monitoring and reporting					
Environmental Rating:	IP55 suitable for outdoor, wet locations					
Dimensions:	330mm x 550mm x 145mm (excluding antenna)				401mm x 600mm x 168mm (excluding antenna)	
Weight:	14kg		15kg		20kg	
Compliances:	C-Tick, CE (refer to website for full product standards matrix)					

Pollution Degree:	3					
Over Voltage Category: AC Mains: DC Input:	 Cat III Cat II					
Max Backfeed Current:	0					
Max Output Fault Current (Continuous RMS):	7.5A	10.0A	15.0A	16.0A	18.0A	21.5A